SPACE SHUTTLE RECOVERY

HEARINGS

BEFORE THE

SUBCOMMITTEE ON
SPACE SCIENCE AND APPLICATIONS

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDREDTH CONGRESS

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**Resigned February 19, 1987 (H. Res. 89).
***Elected March 30, 1987 (H. Res. 133).

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SPACE SHUTTLE RECOVERY: VOLUME I

WEDNESDAY, APRIL 29, 1987

House of Representatives,
Committee on Science, Space, and Technology,
Subcommittee on Space Science and Applications,
Washington, DC.

The subcommittee met, pursuant to notice, at 1 p.m., in room 2318, Rayburn House Office Building, Hon. Bill Nelson (chairman of the subcommittee) presiding.

Mr. Nelson. The hearing will come to order. I have before me a report entitled "Space Operations: NASA's Use of Information Technology." It is an excellent report. It is on NASA operating programs which have not been closely scrutinized by Congress in the past. We are going to use this report as the basis for oversight of NASA's development and use of information technology in the future. There are a few of these reports in the back if you would like to have one.

Well, today we are going to continue our series of hearings on the shuttle recovery effort. The objective is to ensure that when the shuttle returns to flight status, that it will be fully ready to conduct its operations in as safe as possible a manner.

The purpose of the hearings today and follow-on hearings tomorrow is to receive testimony from independent review panels that have been monitoring NASA's recovery. By learning from the insights of these groups, we hope to be better prepared to conduct our oversight responsibilities in this area. We have to maintain vigilance over this program. NASA indeed is well underway to making sure that things are as they should be when we start flying again.

We are going to hear from witnesses from the National Research Council and the Aerospace Safety Advisory Panel. The first witness will be General Alton Slay, who is serving as the chairman of the committee of the National Research Council that is overseeing NASA's highly important efforts in the areas of failure mode and effects analysis, hazard analysis, critical items list, and overall risk assessment and management.

Then we will hear from members of NASA's Aerospace Safety Advisory Panel. This organization, which was created by Congress in the aftermath of the Apollo fire back in 1967, has the responsibility for overseeing the safety aspects of all NASA's manned flight programs. The delegation of panel members that we will be hearing from today will be headed by Mr. Norman Parmet, the deputy chairman of the panel.

We want to thank you all for being with us today, and I would like to turn to our ranking member, Mr. Walker, for his comments.

Mr. **Walker**. Mr. Chairman, I think that we are going to have a valuable hearing today, hearing from some of the independent panels who are monitoring the safety recovery of the shuttle. Some of us are concerned about what the status of the shuttle will be as we move toward that first flight. We are also concerned about some of the things that we still hear coming out of the agency about flight rates and the various component parts aboard the shuttle. I think the hearing today should give us some chance to help clarify some of the questions that are still on the minds of some members of this subcommittee, as well as begin the process of assuring ourselves that in the future we will have safety as the principal concern on all shuttle flights.

Mr. **Nelson**. Okay. Without objection, we will waive the rules and allow the presence of cameras and television cameras.

General Slay, we are delighted to have you.

STATEMENT OF GENERAL ALTON D. SLAY, CHAIRMAN, COMMITTEE ON SHUTTLE CRITICALITY REVIEW AND HAZARD ANALYSIS AUDIT, NATIONAL RESEARCH COUNCIL

General **Slay**. Thank you, Mr. Chairman.

I have prepared a short written statement, and with the approval of you and the committee I would like to enter that on the record and make a few extemporaneous remarks in amplification.

I would like to say to start with, Mr. Chairman, that the relationship of my committee and NASA has been absolutely great. We have been received with a tremendous amount of attention. NASA listens to what we say, and the interface that we have had with NASA has been, I think, one of the highlights for all of the members of the committee.

It is so good that there is very little reason to write a final report, because as we are progressing through our discussions with NASA, they are continually taking action on our recommendations. I think this is the best kind of an oversight committee to have. We always get feedback. They never just accept our comments and go off and do their thing. They always come back to us and talk to us about them. We have had nothing but the most tremendous cooperation from NASA, and I would just like to put that on the record. It has been very helpful to us and has made our job, which could have been tough, much, much easier.

Well, sir, we have been at this now since last September. We have visited all of the related NASA centers. We have visited every contractor that has a significant part in the space shuttle program, and one of them twice. We visited them either in the full committee or in subcommittees of the committee.

We have continued to progress. We have put in one interim report to Dr. Fletcher and we will probably have one additional interim report before our final report, and we are hoping that we can have that final report sometime in mid-fall, at least that is our hope.

In the interim report that we sent to Dr. Fletcher, we raised about seven subjects to discuss with him, and he has responded to each of those officially in a letter that he sent back to us just recently. I guess of most concern to us was the fact that with the job ahead of NASA in handling the recertification and the waiver process that goes along with that recertification—a tremendous job—and with the number of criticality 1 and 1R items that will be facing NASA at the time of the next launch, whenever that might be, we felt that there should be some sort of prioritization program.

At the time that we started our work, all of the criticality 1 items, several hundreds of them, were priority 1. They were all treated exactly the same. Our feeling was that some of these are more likely to occur than others, and we felt that there should be some judgmental process at work to assist NASA in looking at those which had the highest probability of occurrence first and devoting most of their management attention to those, and perhaps allowing some of the less likely events to ride a while until they got around to them.

In conjunction with that, we felt that the use of what we term "probablistic risk assessment" or use of numerical techniques in this decision-making process would be very helpful. We did not suggest at all that NASA substitute numbers-crunching for good, solid engineering judgment, and of course, that recommendation didn't need to be made because obviously NASA would not do that.

What we did say, however, is that when you are considering two separate potential events and you have one that has three zeroes in front of the one as a probability, and another that has two zeroes, then without any regard to the validity of whether the .001 or the .0001 is correct, the delta between the two was important and would put you on the trace of coming up with some sort of prioritization system.

We have discussed both of these problems with Dr. Fletcher and Admiral Truly and their staffs, and they have started—have underway at this time—a procedure that is a prioritization by category, and they have come up with about five categories into which they will place these various potential events. I think that is a tremendous way to handle this. In fact, they already have a de facto prioritization in the fact that they have decided to do some modifications to the shuttle, and those obviously are priority one. So if we can lump those with other things that are the most likely to occur, I believe we can handle this much better.

The second problem related to that—and again, harking back to the tremendous number of these criticality one items—is the actual process for the waiver, for the recertification and waiver process. Now obviously, if there is a criticality one item it either has to be resolved and fixed or it has to be waived before the next flight. Well, in the waiver process we felt that for some of these less likely occurrences, that perhaps level one, which is NASA Headquarters, could delegate that down to level two at Johnson and allow them to handle the waiver process for some of the less likely occurrences or some of the events on the tail end of the line. NASA currently has that under consideration. Dr. Fletcher has written us that they are considering that. I don't know how they are going to come down on it, but again, this is a matter of the degree of attention that can be paid to the several hundreds of these items at level one versus spreading the job out a bit.

We felt that along with this prioritization, with the probabilisitic risk assessment and with the waiver authority delegation, that perhaps it was time the waiver authority delegation, that perhaps it was time to redefine what is a criticality one tiem. We have made several suggestions in that regard, and again, it has to do with the less likely versus the more likely circumstances. We felt that that would be a reasonable thing to do.

One of the things that we brought up with Dr. Fletcher and his staff has been something of a concern about the total integration of their analysis and assessment efforts. We find that when we are looking at an individual piece of equipment, a line-replaceable unit or some element of hardware, that their failure mode and effects analysis, their hazard analysis is very, very good. It's very thorough. And when we're looking within a system, within a subsystem like the main engine or like the SRB, there is ver microscopic attention paid to the integration of all of that.

What we worry somewhat about is the integration of the entire system, including the ground, including the orbiter, including the shuttle motors, the rocket motors and the main engine, all of the related elements in a systems engineering-like consideration. We have discussed this in some detail at all levels of NASA and we have received, again, general agreement that that does need to be reviewed, and it is being reviewed at the current time. NASA has stated that they are looking into their procedures for systems engineering-type overview to make sure that nothing is falling through the cracks, such as the potential of cascading failures, such as the potential of some failure in one system having an abnormal effect in another system that perhaps might get lost without this systems engineering overview.

We hae concerned ourselves somewhat with that appeared to us as a parallelism between the engineering change process and the failure modes and effects analysis/hazards analysis process. We have had our concerns allayed to a considerable extent in that regard.

One of the things that we are still looking at is, is there an adequate interplay between and among those kinds of analysis? Is the failure modes and effects/hazard analysis on the one hand adequately feeding into the engineering change process, and vice versa. If the failure modes and effect analysis over here is operating on an assumption that you have a particular configuration and that does not happen to be the case, then the FMEA is not valid, so we want to make sure that we do have the process in being to adequately integrate all of those efforts, and I believe that that is being done.

We have also been involved in what we call feedback loops—the assurance or attempting to get assurance that all of the data being generated from all tests, from all activity, from all flights, is adequately fed into these analyses. We have again had our concerns allayed in that regard, but there is one thing that we are still looking at.

That more or less takes you up through the interim report number one that we sent to Dr. Fletcher. We have since that time continued to review all of their processes and procedures, and some of the things that we are currently reviewing and currently involved in are design qualification and the flight certification program. We are looking fairly deeply into that. Launch commit criteria and waivers to that launch commit criteria, we have that on our agenda. The process for generating waiver retention rationale, how does that get done? Who is involved in that process? What is the documentation behind that waiver process? We are looking at that.

The NASA new organization for safety, reliability, maintainability and quality assurance program, Saturday we had a thorough briefing by Mr. Rodney on his new organization and how it interfaces with the remainder of NASA. We are very impressed with what we heard, and we will be getting more into detail as to exactly how that is going to affect the way NASA does its business in the future.

The process of structural analysis and estimates of margins we are intending to get into. We have a couple of good structural people on our committee and we are looking at that, as a matter of fact just this week.

We have not as yet been into any detail on the risk management process for software, and we are just now getting into that but it is a major element, that we will not have finished our job until we can satisfy ourselves on how software is managed from a risk point of view. We have had some preliminary activities in that area but we will have a lot more.

Another area where we are just now getting involved is the effect that payloads have on safety. We will be getting into that in some detail to ascertain, do we have an adequate process to assure that there are no adverse effects that are unrecognized, insofar as the payload impact on the total system is concerned.

Well, Mr. Chairman, you have heard me speak a considerable amount about process. We view our job as process-oriented. We are looking principally at policy, procedures and process. We are concerned, obviously, with the output of that process, but we feel that if the process is good, the output is going to be good, so we have attempted to concentrate on the process rather than on the more nitty-gritty, hardware-associated problems.

With that I would just pause, and if you have any questions I will be more than happy to attempt to answer them.

[The prepared statement of General Slay follows:]

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
2101 Constitution Avenue Washington, D.C. 20418

AERONAUTICS AND SPACE
ENGINEERING BOARD

Statement by
Alton D. Slay, General USAF (Ret.)
Chairman, Committee on Shuttle Criticality Review
and Hazard Analysis Audit

before the

Subcommittee on Space Science and Applications
Committee on Science, Space and Technology
U.S. House of Representatives

April 29, 1987

Mr. Chairman and Members of the Committee:

On behalf of the National Research Council (NRC), I am pleased to present our interim findings on Space Shuttle risk management. The NRC committee on risk management for the Shuttle* was formed at the request of the Administrator of NASA as a result of Recommendation III of the Presidential Commission on the Space Shuttle Challenger Accident. Its charge is to assist NASA's effort to improve flight safety and the likelihood of Shuttle mission success.

The Committee presented its interim findings to NASA in a letter report of January 13, 1987, which is attached. This report contains the following points:

1. NASA does not now set priorities for the most critical items in the Shuttle, that is, those components or procedures whose failure would lead to the loss of life or the vehicle. Neither does NASA consider the probability of occurrence of an event in the treatment of these items. The Committee has recommended that NASA devise some mechanism for assigning priorities to these most critical items. It also suggested that the probability of each failure occurring should be an important element of any such priority reasoning.

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* The formal name is the Committee on Shuttle Criticality Review and Hazard Analysis Audit of the National Research Council.

2. Central to the success of any risk assessment process is the certain and timely feedback of system performance and test data to subsequent program decisions, including the risk management process itself. For example, the Committee believes that this information can, if properly used, assist greatly in NASA's Failure Modes and Effects Analyses, the derivation of the list of critical items, and hazard analyses, as well as in the determination of the priorities of the critical items.

3. We believe that the use of quantitative techniques as an input to the risk management process could provide a more realistic assessment of risk, at least on a relative basis. However, we do not wish to suggest that NASA subordinate technical judgment to numerical analysis. Such an approach would be, in our opinion, unrewarding and perhaps counterproductive. Nevertheless, appropriate numerical techniques can give NASA a further indication of the relative importance of different courses of action as an aid in the exercise of technical judgement.

4. Waiver authority for all of the most critical items now rests with NASA Headquarters. The Committee believes that Headquarters should focus its attention on the most important items, determined by the suggested use of priorities of the critical items, and delegate decisions on the others to lower management levels.

5. The Committee noted that there are a variety of items which, by precise definition, must be placed in the most-critical items category. Since many of these items differ substantially in terms of the probability of failure, the Committee has suggested that NASA consider modifying the current definition of critical items to account for these differences and better focus the efforts of NASA to achieve safer Shuttle operations.

6. Several components of NASA's risk management process deal with the interactions between Shuttle subsystems and elements, and their integration into the the Space Transportation System (STS). However, the Committee is concerned that there may remain some potential gaps from the perspective of the STS as an integrated system. Therefore, the Committee has suggested that NASA incorporate such an integrated STS analysis and assessment process in its risk management system in order to assure assessment of the truly critical safety elements in the STS.

7. Finally, the Committee noted that many engineering changes have been undertaken since the Challenger accident to improve Shuttle safety prior to resumption of flight. These changes are being introduced in parallel with the reevaluation of the Shuttle Failure Modes and Effects Analyses, the list of critical items, and hazard analyses. Thus, the Committee has recommended that NASA assure a close linking between the STS engineering change activities and this reevaluation process.

The Committee is continuing its audit by examining other aspects of the Shuttle risk management process. Among these are the:

- design qualification and flight certification processes;

- launch commit criteria and waiver policy;

- process of generating, reviewing, revising and approving the retention rationale for waivers to permit flight of Shuttle with critical items that affect safety;

- NASA Safety, Reliability, Maintainability and Quality Assurance program;

- process of structural analyses, establishing margins, and verification of the analyses and margins;
- risk management process for Shuttle software; and
- process for analyzing the effect of payloads on the safety of the Shuttle and its ground and flight crews.

We expect that a final report of the Committee will be submitted to NASA late this year. It will include our assessment of procedures reviewed and recommendations for improvement of the Shuttle risk management system. As appropriate, findings and recommendations from these reviews also will be supplied promptly to the NASA Administrator in the form of interim letter reports.

While we recognize that it is not possible a priori to guarantee mission success and flight safety, through this review and audit we hope to assist NASA in taking those prudent steps which will provide a reasonable and responsible level of assurance of flight safety for the Space Shuttle. The Committee has been favorably impressed by the dedicated effort and beneficial results obtained thus far by NASA and its contractors from the risk management system. We are very appreciative of the frank and open manner in which they have worked with the Committee. Our suggestions have been received in a very responsive manner as exemplified by Dr. Fletcher's response to the Committee's letter report, which is attached.

Mr. Chairman, this concludes my statement and I will be happy to answer questions.

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
2101 Constitution Avenue Washington, D.C. 20418

AERONAUTICS AND SPACE
ENGINEERING BOARD

January 13, 1987

The Honorable James C. Fletcher
Administrator
National Aeronautics and Space Administration
Washington, D.C. 20546

Dear Jim:

This is an interim progress report of the Shuttle Criticality Review and Hazard Analysis Audit Committee. The National Research Council formed this committee in response to your request for an audit of the NASA response to the Presidential Commission Recommendation III regarding criticality review and hazard analysis.

The Committee has been a functioning entity since its first meeting on September 22, 1986. We have thus far received presentations from and engaged in detailed discussions with NASA Headquarters, the National Space Transportation System program office, Johnson Space Center, Marshall Space Flight Center, and Kennedy Space Center. Similar meetings were held at Rocketdyne (Space Shuttle Main Engine) and Rockwell International (Orbiter), and by a working group at Morton Thiokol (Solid Rocket Motor). All of the participants described their efforts and progress in reevaluating the Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL) status and in reassessing hazard analysis and risk management. The Committee also has received a briefing on and discussed the process being used by the U.S. Air Force Systems Command-Space Division to determine launch readiness and safety status. The Titan 34D Recovery Program was described as an example.

The Committee has been favorably impressed by the dedicated effort and extremely beneficial results obtained thus far from the FMEA/CIL and hazard analysis processes. We are very appreciative of the frank and open manner in which NASA and contractor personnel have worked with the Committee. Our suggestions have been received in a very responsive manner in all quarters. We wish to commend Admiral Truly, Arnold Aldrich and the NASA Shuttle team involved in the FMEA/CIL-hazard analysis processes for the significant work they have performed so far. Although our general impressions are favorable, we do have some suggestions for improvement. In summary, they are:

- o Criticality 1 and 1R items should be assigned priorities based on the probability of occurrence.
- o Since many of the Criticality 1 and 1R items differ substantially in terms of the probability of failure, NASA should consider modifying the definition of critical items to account for these differences.

- o NASA should incorporate its present total system review procedures in an integrated systems assessment process coupled closely with the FMEA/CIL reevaluation now being undertaken.
- o Linkage between the STS engineering change activities and the FMEA/CIL-hazard analysis processes should be assured.

SETTING PRIORITIES FOR CRITICALITY 1 AND 1R ITEMS

NASA does not now set priorities for Criticality 1 and 1R items nor does it consider the probability of occurrence of an event in the treatment of these items. The Committee recommends that NASA devise some mechanism for and assign priorities to the Criticality 1 and 1R items. It suggests that probability of occurrence should be an important element of any such priority reasoning. Basing priorities on this fundamental measurement of risk will help NASA and those interested in its progress to evaluate the adequacy of changes being made to Shuttle hardware, software, or procedures in the interest of enhancing safety.

Essential to the success of any risk assessment process is the certain and timely feedback of preflight and postflight system performance data, along with test data and failure or degradation reports. Such inputs are critical to any successful FMEA/CIL and hazard analysis program and can form the basis for more precise evaluation of risk. While it is clear to the Committee that these data are used in readiness reviews and other NASA activities, it is not clear that they are used in the FMEA/CIL or hazard analysis processes. The Committee believes that this information can, if properly used, assist greatly in the FMEA/CIL and hazard analysis processes and in the determination of priorities.

The present decision-making process within NASA with regard to FMEA/CIL appears to be based on the judgment of experienced practitioners and has received very little contribution from quantitative analysis. We believe that the failure of NASA to use numerical techniques as an input to decision-making detracts from the overall effectiveness of the FMEA/CIL and hazard analysis processes. Such techniques could provide a more realistic assessment of risk, at least on a relative basis. We do not wish to suggest that NASA subordinate technical judgment to numerical analysis. Such an approach would be, in our opinion, unrewarding and perhaps counterproductive.

Currently waiver authority for all Criticality 1 and 1R items rests with NASA Level I. The Committee believes that Level I should focus its attention on the highest priority items resulting from the suggested selection process, along with the rationale that produced the priority rating. The waiver decision authority for the remainder of the Criticality 1 and 1R items should be delegated to Levels II and perhaps III.

DEFINITION OF CRITICALITY CATEGORIES

The Committee notes that the dedicated response of the entire NASA organization and its contractors has produced a variety of items which, by precise definition, must be placed in the Criticality 1 or 1R categories. Many of the items differ substantially from one another in terms of the probability of failure or malperformance and thus their potential impact on Shuttle operational safety. The Committee suggests that NASA consider a modification of the Critical Items List to account for these differences, help the priority selection process, and better focus present or future efforts to achieve safer Shuttle operations.

INTEGRATED SPACE TRANSPORTATION SYSTEM ANALYSIS

The Committee understands that various mechanisms are being used by NASA to examine total system operation, including propagation of failure modes to interfacing or physically adjacent modules or subsystems. The Committee does not perceive, however, any formal relationship of such evaluation methods to the ongoing FMEA/CIL process. The Committee suggests that NASA devise an integrated STS systems assessment process which is closely coupled with the FMEA/CIL activity to assure assessment of the truly critical safety elements in the STS. This includes all combinations of hardware/software/procedural failures and cascading failures.

RELATION BETWEEN FMEA/CIL-HAZARD ANALYSIS AND DESIGN CHANGES

We note that many engineering changes have been undertaken since the 51-L accident to improve Shuttle safety prior to resumption of flight, now scheduled for February 1988. In parallel, the FMEA/CIL and hazard analysis reevaluations are under way with completion expected during the summer of 1987. Thus, the FMEA/CIL reevaluation may not adequately reflect all of the engineering changes, nor will there be time to incorporate any substantial design changes that may be indicated by the outcome of the FMEA/CIL reevaluation, hazard analyses, and related activities. The Committee recommends that NASA assure a close linking between the STS engineering change activities and the FMEA/CIL-hazard analysis processes.

FUTURE WORK

The Committee is continuing its effort to audit the FMEA/CIL, hazard analysis, and related processes dealing with risk assessment. We have planned additional visits to NASA centers and contractor facilities where we will continue to examine the mechanisms used by NASA and its contractors to provide for the overall safety of the STS as an integrated system. We also will further refine some of the points raised here in future reports to you. While we recognize that it is not possible a priori to ensure mission success and flight safety, through this review and audit we hope to assist NASA in taking those prudent steps which will provide a reasonable and responsible level of assurance of flight safety. We will, of course, remain in close contact with your staff throughout this activity.

Sincerely yours,

Alton D. Slay
Chairman
Committee on Shuttle Criticality
Review and Hazard Analysis Audit

cc: Admiral Richard H. Truly

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National Aeronautics and
Space Administration
Washington, D.C.
20546
Office of the Administrator

APR 22 1987

General Alton D. Slay
National Research Council
National Academy of Engineering
2101 Constitution Avenue, NW (NAS 307)
Washington, DC 20418

Dear Al:

In reply to your January 13, 1987, interim progress report of the Committee on Shuttle Criticality Review and Hazard Analysis, your four suggestions are repeated, along with NASA's response to each.

NRC Comment: "Criticality 1 and 1R items should be assigned priorities based on the probability of occurrence." (This comment also suggested the use of probability analysis techniques and the delegation of certain criticality items to lower levels of the organization.)

NASA Response: The National Space Transportation System is in the process of selecting and implementing a critical items prioritization technique for the Shuttle program. Five different techniques have been evaluated by review teams at JSC, MSFC, and KSC. One of these techniques has been selected to be presented to the program manager at a Program Requirements Control Board (PRCB) for baselining as a formal program requirement. The chosen approach will overlay the existing Failure Mode and Effects Analysis/Critical Items List (FMEA/CIL) activity with minimum perturbation, yet provide an effective measure of relative risk in order to focus future review emphasis and resource allocations. In parallel with the prioritization technique development, an effort is also under way to assess the utility of probabilistic risk assessment in the NSTS FMEA/CIL process. Activities have been initiated to engage two independent firms with expertise in probabilistic risk assessment to perform detailed reviews of the orbiter auxiliary power unit and the shuttle main propulsion pressurization system. A decision to apply such probabilistic risk assessment techniques to other elements of the Shuttle will depend upon assessments of the results and impacts of those efforts and comparison of these results with the results of the mainline FMEA/CIL activity. Delegating the review and approval of certain critical items will be decided after the results of the prioritization and risk assessment activities have been thoroughly assessed.

NRC Comment: "Since many of the Criticality 1 and 1R items differ substantially in terms of the probability of failure, NASA should consider modifying the definition of critical items to account for these differences."

NASA Response: We expect the FMEA/CIL prioritization process will provide the necessary definitions and program focus in this regard.

NRC Comment: "NASA should incorporate its present total system review procedures in an integrated systems assessment process coupled closely with the FMEA/CIL reevaluation now being undertaken."

NASA Response: Since the Challenger accident, NASA has reemphasized its risk management effort. An important feature of the revised effort must be a "systems engineering" approach that integrates the various elements of the risk management process to assure assessment of the combinations of hardware, software, procedures, and cascading failures. NASA's new Associate Administrator for Safety, Reliabilility, Maintainability and Quality Assurance has been tasked to develop a new agencywide risk management system.

NRC Comment: "Linkage between the STS engineering change activities and the FMEA/CIL hazard analysis processes should be assured."

NASA Response: Engineering changes are processed through the same Space Shuttle configuration control boards that conduct the review of the FMEA/CIL. A recent change to the procedure requires an assessment of each change request to determine if it affects any Criticality 1 or 2 hardware. The nature of the combined change control and FMEA/CIL processes is such that the total process cannot be completed until the last change to be implemented before flight has itself undergone a FMEA and been dispositioned by the board. Regardless of the timetable established by the NSTS working schedule for FMEA/CIL preparation and review, the changes that result will be dealt with in the same manner as the generating FMEA items. All changes mandatory for first flight will undergo the same rigor, even if this results in a flight schedule impact. The NSTS Systems Design Reviews which began early last year have significantly reduced the likelihood of new changes being identified that have major schedule impacts.

The dedication of your committee and the sincerity of its comments are very much appreciated by NASA. I hope you find our actions in response to your suggestions to be both appropriate and timely. Thank you again for your help.

Sincerely,

Jim F

James C. Fletcher
Administrator

Mr. NELSON. Mr. Walker.

Mr. WALKER. Thank you, Mr. Chairman.

Thank you for your statement, and I thank you for including as a part of your statement the letter that you had sent to the Administrator with regard to your first update.

In reading through that material, I was somewhat troubled by one thing that you were pointing out, and I want to find out whether or not I understand it or whether I have a misunderstanding here. It seems to me that you are saying that the vehicle that we will fly on the first flight, once shuttle has recovered, will be a substantially changed vehicle from that which we have flown before, I think we all acknowledge that, as a result of the changes.

However, it also sounds to me as though, at one part here on page 3, you are suggesting that the evaluation with regard to failure modes and effects and so on may not adequately reflect all of the engineering changes. Now are——

General SLAY. No, you have said it correctly but perhaps more strongly than we meant it. This goes back to the point of the parallelism between the engineering process and the failure modes and effects analysis process. Say that these changes are continuing to be made up, say, until this fall and next spring, and we don't take care to assure that we go back and redo the failure modes and effects analysis, hazard analysis. Then the circumstance that you bring up would apply. We would want to make certain that we have gone adequately on record that this has to be done, that this interplay among the analyses on one side and the engineering change process on the other actually takes place.

Mr. WALKER. Well, I think that is a valuable point to have made here. Are you assured at this point that that is the intent, that each time one of these changes is made in the vehicle, that there is going to be a full reassessment of how that particular change affects the entire system?

General SLAY. We have been completely assured of that, Mr. Walker, and what we are up to now is certifying that that process is actually in effect and in place.

Mr. WALKER. So that as we add things like a crew evacuation process——

General SLAY. Yes.

Mr. WALKER [continuing]. Which will involve putting additional explosives aboard the vehicle, we are going to take a look not only as it affects the structure of the vehicle and the obvious things that could result from that kind of explosive device being aboard the vehicle, but also the fact that it may also have ramifications for the entire system, and so they will go back through and look at the entire system as it maybe effected by that crew evacuation process?

General SLAY. That's correct. We strongly believe that that is essential, as I believe NASA feels that that is essential.

Mr. WALKER. Okay. That helps clarify that. Have you done any analysis of flight rates or potential flight rates?

General SLAY. No, we have not, sir.

Mr. WALKER. So you have not looked into the question of whether or not the flight rate that is currently being projected by NASA at 16 flights a year is an appropriate number?

General SLAY. No, sir. That was not within our charter. We have not looked at that at all.

Mr. WALKER. Let me think here.

I will yield back at this point, Mr. Chairman.

Mr. NELSON. General, you know what NASA has proposed in the way of fixes to the flight hardware. Do you want to give us your opinion about that?

General SLAY. Yes, sir. I think those are very well considered and needed engineering changes. I have seen nothing in what they are doing that would cause me the least bit of concern. I think that they have done an extremely fine job of looking at this from an engineering point of view. We have found nothing at all to indicate to us that they are on anything but the right track.

Mr. NELSON. Well, of those fixes, they are trying to categorize them.

General SLAY. Yes.

Mr. NELSON. Category 1, it would have to be a fix prior to launch; and a category 2, as soon as possible; and then a category 3, when convenient. Are you satisfied with those categories?

General SLAY. I am satisfied with the categories. There may be some discussion, obviously, as to what fits in those categories, but we have not really involved ourselves with that to this point. I do believe that it is necessary to come up with categories like that because it is quite obvious that some of these things are fine to do and could be put off, but others that are safety-related need to be done before the first flight.

Mr. NELSON. Do you have any advice for us? One of the policy questions that we have to face is NASA's determination that they should move forward with a block two on what they call an advanced solid rocket motor. Under their timetable, it would be ready somewhere around the middle of the 1990's; that is as opposed to the present fix we are talking about on the existing solid rocket motor.

General SLAY. Yes.

Mr. NELSON. Do you have any advice to us with regard to that?

General SLAY. I think that is a wise move, Mr. Chairman. You know, obviously this is, the fix that they are going with now is making maximum use of the existing hardware, and I think that's a wise thing to do. The final fix obviously will be something that is much more suitable for the long term. I see nothing wrong in what they are doing.

Mr. NELSON. So you are satisfied from an engineering standpoint, from your standpoint as chairman of the overview panel, that the fix that they are proceeding with on the solid rocket booster is in fact what is needed to get us until that time that we have a replacement with an advance?

General SLAY. Now as I am sure you know, we as a panel did not look into that specifically because there was another NRC panel looking at that, and I am sure you have heard from them or will hear from them. I would not want to answer that as a member of the committee, as chairman of the committee. I could answer it as Al Slay, private citizen. From what I know, yes, I think that had I been in a decisionmaking position, I would probably have said that's probably as good as we can do and not delay this thing for another five or six years.

Mr. **Nelson**. And in speaking as a private citizen, when you say "as good as we can do" you're talking about it's adequate to get us to the point of an advanced solid rocket motor?

General **Slay**. That's right. That's correct, yes.

Mr. **Nelson**. So to recapitulate, you are saying that NASA's identification of the deficiencies in the design or the performance, you think that they are correcting those in the way that they should?

General **Slay**. Yes.

Mr. **Nelson**. All right. Now what about safety margins? Take, for example, the main engines, running them at 104 percent or 100 percent, does your committee have a feeling of what power setting those main engines ought to be run at?

General **Slay**. Well, obviously they are supposed to be run at 109 percent and, I think, at 100, 104 percent. Again, a personal belief is that that is an adequate margin. We have not looked at that from a committee point of view. Again my answer has to be from a private point of view. We are looking at failures more than we are at power levels, potential failures.

The failure modes and effects analysis assumes a failure of some component, and then we allow that to grow and see what might happen. Whether or not that failure occurs at 100 percent or 104 or 109 percent is of no consequence to what we have been doing. We have been looking at the fact of a failure and what would happen if that failure occurred, and then the process for handling that administratively. How do you do that? How do you look at that potential failure and come to grips with it from an analysis point of view?

Mr. **Nelson**. Let me go back, before I turn to Mr. Packard, and do a question on a follow-up to the question about the categories of the fixes. You said that you were satisfied with their different categories—that some fixes have to be done prior to launch, others as soon as possible, and then others when convenient. Do you have a feeling about what NASA used as a criteria to determine those categories, how important the fix was or how easy it would be to make the fix?

General **Slay**. Well, it's hard to quantify something like that, Mr. Chairman. I am sure that they did exactly what I would have done or you would have done in similar circumstances, look at not only what might happen if we had a failure in that area but what is the likelihood of that occurring, and attempted to establish some prioritization system, very much like we are recommending on the criticality items.

I do not know specifically what rationale they used for putting things in those different categories, but I can imagine what they might have been. I would think that were I doing it, in a management point of view I would attempt to prioritize myself, knowing that these things all cannot be done and have a launch at a reasonable time.

Mr. **Nelson**. Mr. Packard?

Mr. **Packard**. Thank you, Mr. Chairman.

General, welcome to the committee. What changes would you suggest in the utilization of the shuttle from what we were doing previous to the *Challenger* accident, in terms of ELV's, flight rates, et cetera? How would you balance that formula as we look toward relaunching?

General SLAY. I will be glad to try to answer that, again not as the chairman of this committee, because we didn't look into that, but I will be glad to share with you my bias in that regard as a person.

Mr. PACKARD. Please.

General SLAY. Obviously the reliance on the shuttle for launches is a thing of the past. I mean, we cannot afford in my opinion to rely on one mode of transportation to space. We must have ELV's, and I believe that most everyone in the business has come to a similar conclusion. It is quite clear to me that with a reduced shuttle fleet, that has to be on the top of everyone's mind: What can we do on shuttle? What do we most logically want to do on shuttle, versus the expendables?

I feel that we will feel our way in this, and I know that in my old service, the Air Force, we have come to grips with this and have clearly established a policy that says that we will do a considerable amount of space transportation with expendables instead of planning 100 percent on shuttle as we were at one time. I think this is a wise move. I believe that NASA is moving in that direction, and I applaud that move, as a private citizen.

Mr. PACKARD. Do you feel that the reverse of that policy, that is, 100 percent of those payloads that do not require manned shuttle capabilities, ought to be launched on ELV's so that only the shuttle will be used—I should say the shuttle would be used then only for those that require the special capabilities of the shuttle?

General SLAY. Well, that to me, Mr. Packard, is the point of departure. You obviously want to do those kinds of missions first. If you have the safe capability to do other missions, I think that that is a reasonable thing to do from an economic point of view, but obviously you don't want to press into that non-manned related payloads at the expense of heavy flight rates that are not safe. What I'm saying is that you start with those payloads that do require men and you schedule those for shuttle. Anything you have left over in a reasonable flight rate could easily be put on shuttle, and I think it would be advantageous.

Mr. PACKARD. Would you believe or feel that there would be more than enough payloads requiring shuttle capabilities to fill the projected or proposed flight rate?

General SLAY. I haven't really looked at that, Mr. Packard. My inclination would be—a totally untutored inclination—would be to say that knowing the kinds of payloads that we have launched over the past 10 years and the kind that we are likely to launch, I would say a considerable number of those would benefit from man's presence on the shuttle. But, again, that is an untutored assertion on my part.

Mr. PACKARD. NASA has not—well, maybe I ought not to say that. Would you suggest that NASA ought to take a more aggressive role in the procurement of ELV's and, if so, how would you suggest they go about it?

General **Slay**. Again, Mr. Chairman, I would be glad to answer the question but not as the chairman of my committee because we have not looked at that. If by terms of the term "aggressive" you mean should NASA be aggressively pursuing the ELV option, I would say absolutely yes, they should be aggressively pursuing that option. Whether or not you mean by "aggressive" doubling their effort or tripling their effort, I am not prepared to say, but I think it is a wise thing as a private citizen I would recommend that NASA do. I believe, from my knowledge of what NASA is doing, that they are proceeding with some deliberate speed in this direction of ELV's.

Mr. **Packard**. I think my question probably was promoted by the concept that we have not seen in the budget request funding for ELV's.

General **Slay**. I see.

Mr. **Packard**. I was wondering if in fact you feel that there should be some adjustments there or perhaps some type of request for special funding for ELV's.

General **Slay**. I will have to pass on that, Mr. Packard. I really haven't reviewed that.

Mr. **Packard**. I understand.

Mr. Chairman, I won't take further time for further questions.

Mr. **Nelson**. Mr. Volkmer?

Mr. **Volkmer**. Thank you, Mr. Chairman.

General Slay, just so that I have a better understanding of the work that you all have done—I think I do—of the National Research Council in this regard, is it generally you phrase it that you did a methodology of determining or better determining risk assessment in general, as far as items, but the committee did not look into specifics within those like criticality 1 items, et cetera?

General **Slay**. Yes. We are looking—we have attempted to steer clear, as much as we can, of hardware. We have dealt in process and procedures rather than hardware.

Mr. **Volkmer**. Right.

General **Slay**. We feel that the process just has to be good or the actions on the hardware will not be good, so we are looking at the process first. Now obviously we have gotten into some considerable amount of detail on hardware, but that has not been our primary focus. Our primary focus has been on things other than hardware.

Mr. **Volkmer**. That's what I thought, and I want to commend you for it. I noticed in the letter from Administrator Fletcher that they are pretty well incorporating those principles.

General **Slay**. Yes.

Mr. **Volkmer**. Now maybe somewhere I got the impression that there is a recommendation that you do perhaps a quantitative analysis along with it?

General **Slay**. That's correct.

Mr. **Volkmer**. Now couldn't that possibly get us into difficulty?

General **Slay**. No, sir, not if it's done right.

Mr. **Volkmer**. I would like to elaborate on it, what I see. All right?

General **Slay**. Yes.

Mr. **Volkmer**. Because what I see of what happened to the *Challenger* is a little bit—in other words, we got away with it 23 times and so we can waive it now because it didn't happen. When we get into the quantitative, aren't we getting into that?

General **Slay**. No, sir, not at all.

Mr. **Volkmer**. All right. Tell us about it, then.

General **Slay**. That is a common misconception of probabilistic risk assessment. If I even had the remotest thought that the kind of thing like you just said would occur, we would never, ever have recommended probabilistic risk assessment. What we are suggesting is that there is a body of knowledge that has been growing over the past 15 or 20 years on how to do this kind of analysis. It is not saying, "All right, we have had 23 flights. Therefore it is safe to have another." That is not probabilistic risk assessment. Even to the extent of saying that, you know, "We did 15 tests and we had one failure in those tests," that is saying that you have 1 in 15 chances of having a failure, that is not probabilistic risk assessment.

What we are saying is that there are techniques to go in and take a piece of hardware or a system or a subsystem and review that in tremendous detail as to all of the interactions of the various parts within that system, and come to some conclusions as, "This has a probability of failure of so-and-so and so-and-so." Now one of the points that we——

Mr. **Volkmer**. Could I interrupt just right there?

General **Slay**. Yes.

Mr. **Volkmer**. When you say "so-and-so and so-and-so," is that the quantitative?

General **Slay**. No, that is not yet——

Mr. **Volkmer**. What are you saying when you say "so-and-so"?

General **Slay**. That's part of it.

Mr. **Volkmer**. All right.

General **Slay**. But the essential part is that what we are recommending is that NASA do that on these systems and subsystems and piece parts, and not come to any specific conclusion based upon the number of zeros that are in front of the 1 of the probability of failure. We think that would be a grievous error to do.

What we are saying, probabilistic risk assessment from a management point of view is a tool. It helps you to direct your attention on something that is more likely than something else. It doesn't say that the discreet numbers that you come up with are, in and of themselves, correct. What we are suggesting is, it is the delta between and among those numbers, the difference in those numbers, that is important as far as prioritization and focus of attention is concerned, and that is what we are recommending.

Anything else that might be implied in what we are recommending is just not there, sir. We are not recommending that you take these numbers and say, "This is absolute ex cathedra. This number, if it came out say .01, on the 100th mission you are liable to have that fail." We don't believe that.

Mr. **Volkmer**. All right. Then you are basically relying on total what, technical judgment, then?

General **Slay**. Absolutely. You must rely on technical judgments, good, sound engineering judgments, but we think that these engineering judgments can be better applied by using this tool to help focus that engineering judgment.

Mr. VOLKMER. All right. Now my question then is, within the NASA establishment, whether it is headquarters or whether it is at Kennedy or Houston or wherever, do we have the engineers that are qualified to properly exercise that technical judgment?

General SLAY. Yes, we have. I thought you were going to ask me another question and I'm glad I didn't answer it earlier. I thought you were going to ask do they have the statistical engineering capability, and I was going to answer that no, but I can answer what you just said as a resounding yes. They do have that kind of technical judgment.

Mr. VOLKMER. Well, you are asking them to get away from the statistical, are you not?

General SLAY. No. I am asking them to use statistical analysis as a tool, as one arrow in their management quiver.

Mr. VOLKMER. But not to be the final decisionmaker.

General SLAY. Absolutely not.

Mr. VOLKMER. In other words, if it is 1 in 10 thousandths chance it is going to happen, that means we go ahead and fly, but if it is 1 and 10, we don't fly, you don't want that as a final.

General SLAY. No. What we want——

Mr. VOLKMER. But that would be part of the total.

General SLAY. Part of—they would take that 1 in 10 result and say, "Great Scots, I better look at that with much more detail, in much more detail, than I will look at the 1 in 10,000." The 1 in 10,000 and the 1 in 10 are two entirely different ball parks.

Mr. VOLKMER. Right.

General SLAY. So if it were me in an engineering management position, I would say I want to focus on that 1 in 10 and assure myself that what we have done is correct and we don't need to do something else. I would perhaps put the 1 in 10,000 off until tomorrow.

Mr. NELSON. Mr. Volkmer, let me get you to take the Chair. I have some testimony in front of the Appropriations Committee that should only take me about 5 or 10 minutes.

Well, there are the bells, so——

Mr. VOLKMER. I am almost—let me ask one more question and I will be finished, and perhaps we can finish with General Slay and then go vote, and I will come back.

Mr. NELSON. sure.

Mr. VOLKMER. On that, this basically means that a lot of it is going to be judgment call, then.

General SLAY. That's correct, sir.

Mr. VOLKMER. I am not an engineer. My past experience has been as an attorney. I don't think we've got very many engineers on this panel. How do we do oversight over that judgment?

General SLAY. Well, that's a very difficult thing.

Mr. VOLKMER. How do I second-guess an expert that I don't know anything about?

General SLAY. Well, that's the reason I have never envied congressional committees. They have to do that, and it's a very difficult thing. You have to get as best educated as you can on the engineering circumstance of the decisions that are being made and make judgments on that, but obviously it is a judgmental process, and I would certainly never want to try to recommend that we substitute numerics for engineering judgment. That would be a disaster.

Mr. VOLKMER. Thank you very much.

Mr. NELSON. Before we recess the committee, I rather suspect what this is, is this is a quorum call prior to the vote on the Gephardt amendment, and I imagine that they are reserving some time for the final speeches on the amendment. So let me recommend, let's go vote on the quorum call, and if I could get you to take the Chair and resume the hearing.

General Slay, I have a series of questions that I need to ask you. May I ask you to remain so that the other panel can go ahead and proceed, and then when I return I would like to resume asking you some additional questions, as I also intended to direct it to the panel. Could you do that?

General SLAY. Yes, indeed.

Mr. NELSON. Very good.

The committee will stand in recess.

[Recess taken.]

Mr. VOLKMER [acting chairman]. The subcommittee will resume its hearing, and we will take the second panel: Mr. Norman R. Parmet, deputy chairman, Aerospace Safety Advisory Panel of NASA. He is accompanied by Mr. John Stewart, Melvin Stone, Seymour Himmel, Norris Krone, and Charles Donlan.

Mr. Parmet, your statement will be made a part of the record in full in at this point in the record. You may either review it in full or summarize. We have approximately, I have been told, about 20 or 25 minutes before we get to another roll call vote.

STATEMENT OF NORMAN R. PARMET, DEPUTY CHAIRMAN, AEROSPACE SAFETY ADVISORY PANEL, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, ACCOMPANIED BY JOHN STEWART, MELVIN STONE, SEYMOUR HIMMEL, NORRIS KRONE, AND CHARLES DONLAN

Mr. PARMET. Well, I won't take more than about 10 minutes to summarize. I guess the first thing I have been asked to explain is how the heck I got this black eye. You won't believe it, but I was told to tell you that we had some disagreements among our panel but you should see the other guys. [Laughter.]

It actually happened on the tennis court.

Mr. VOLKMER. Well, that's different than a doorway.

Mr. PARMET. I am deputy chairman of the Aerospace Safety Advisory Panel. Our chairman, Mr. Joe Sutter, is unable to be with us today. He has written a letter to your committee, the sum and substance of which I can summarize quite briefly: It is safety first and schedule second.

Now in addition to Mr. Sutter's letter, we have delivered our annual report about a month ago, and on Friday we delivered the written report of this panel that responds to some questions that came from your committee. We had our annual meeting on March 11th, and at that time we reviewed the annual report with NASA's administrator.

Our report to you responds to a number of specific key points which are essentially these: What have the contractors and NASA done well? Secondly, if improvements are needed in the recovery program, what should they be and how best to implement them? The third one, what advice does the panel have for the Congress in its oversight role which can support such improvements?

Now our response is in your hands and I intend to provide a brief summary of some of the highlights, but first I would like to give you a little bit of the panel background.

During the past year, panel members and consultants were involved in about 50 visits to NASA Headquarters, to all the centers, to their major contractors. We have been represented on National Research Council panels. We have been involved with independent oversight groups. We have supplied information to the presidential panel and we have supplied information to your committee, the House Committee on Science and Technology, to its investigation team.

There are five members of our committee along with me. Their names are in front of you, and when it comes to the question and answer session I am going to refer to the guy who knows the most about the subject and let him respond.

In general we believe that NASA is heading in the right direction. A number of management changes have already occurred which should strengthen the organization. In particular, the establishment of the new Office of Safety, Reliability, Maintainability and Quality Assurance is a mouthful in itself, and with an administrator at its head and with corresponding changes at the NASA centers, we believe this will strengthen NASA's ability to meet present and future challenges.

We do have some words of caution, however. I have heard, "Leave it to George" a few times. Now George Rodney is the new associate administrator. Our words of caution are essentially related to the placing of excessive reliance on the shoulders of this one organization. It's got to be a team effort. You can't leave it only to one guy because you're very quickly going to overload him. Besides that, we believe very strongly that quality and safety must be built in. It's hard to inspect stuff in after you've got a design and you have delivered the product.

The next subject Al Slay has talked about extensively, and it's hard to follow an act like his but I just would recap briefly that we see NASA doing a significant amount of reanalysis on all elements in the STS program. They have had a heck of a lot of manpower expenditure going into failure mode and effects analysis [FEMA], hazard analysis [HA], et cetera.

We also believe that NASA needs to provide some additional analytical tools to help them prioritize the problem areas in an effective manner. We support General Slay's view that probabilistic risk assessment may be the additional tool that will help in this area. If you have any further questions on that, we will be prepared to try to field them later.

Now I mentioned that we are working outside as well as on the panel. A number of us are or have been working with the National Research Council on their shuttle audit panels. Mel Stone, right here, is on the NRC panel for evaluation of the redesign of the solid rocket booster. Gerry Elverum, who was supposed to be here today but could not attend because of illness in his family, and I are on the shuttle criticality review and hazards analysis audit committee. These titles are a mouthful to get out. I have suggested some shorter names but I have been rejected. We have also had representation on the shuttle flight rates and utilization panel. I was on that panel. That committee has completed its task.

Now specifically to the solid rocket booster, we consider the redesign of the field joint a marked improvement over the original design. We believe that proof of its adequacy, however, depends strongly on satisfactory results from a thorough test program. We understand NASA has recently reinforced that program, and we applaud their decisions in that area because we keep remembering—and I want to emphasize—safety first, schedule second.

In the long run, for higher margins of safety we believe that NASA should proceed with aggressive development of the Langley and Hercules concepts or their equivalent for the case field joint and the nozzle-to-case joint. In other words, down the road we feel there ought to be a better design for a more permanent fix.

We have commented on a number of areas on the orbiter and have recommended a flight readiness firing, and NASA has recently approved the flight readiness firing.

The main engines have received considerable attention. Although they will be in the phase 2 configuration, we have recommended that they be constrained to operate at no more than 104 percent of rated thrust, unless if the payload would permit, except under emergency conditions. If you lose an engine, we say okay, you can go to 109 percent because you have no other choice at that time.

I haven't touched upon many items in the interest of keeping my verbal comments reasonably short, but in our written report we have talked about launch processing systems, mission control and flight operations, ELV, nondestructive testing, computers and software, and crew escape.

I have several concluding observations on other related issues that can affect safety either directly or indirectly. The dangers involved in initiating and sustaining a high-tech, high-cost development program in a political environment where each annual budget is a life-or-death proposition are real, and the temptations toward exaggerating the benefits underrating the costs and problems are great.

This problem of truth in budgeting compounds when officials and managers actually begin and start to believe their own sales rhetoric. Technological reality that conflicts with the political rationale is often kept at arms length. In addition, as resources and schedules are stretched, individual managers often focus on keeping their small part of the program alive. Fewer and fewer persons pay attention to the larger stakes, the bigger picture.

People assume that problems will make their way up the bureaucratic chain of command. That often doesn't happen. A bureaucracy instinctively avoids passing along bad news. Accountability is allowed to become unclear and diffused. External political and budget pressures eventually wear down good judgment and common sense. These many factors eat away at good management practices, traditions and structures.

Finally, there is always the danger of—and I like this term—oversight gridlock—the situation where institutionalized second-guessing through myriad review panels, oversight committees, investigative bodies and the like dilutes the sense of responsibility, discipline and accountability that properly resides with line management. Safety is principally the result of disciplined, careful design, systematic testing and evaluation of the design, faithful construction or manufacture, full knowledge of the system's strengths and weaknesses, and the discipline and dedicated performance of people.

The danger in placing undue reliance on an elaborate structure of review and oversight groups is that it can become a justification for not doing the job correctly in the first place. "Not to worry," says the manager, "the reliability and QA guys will catch that down the line." I don't believe in that. Our panel doesn't believe that is the way to operate.

Well, as I said, our report contains a lot more than I have spoken of verbally, but we would like to turn it back to you and we'll see if we can't field all the questions you throw at us. Thank you very much.

[The prepared statement of Mr. Parmet follows:]

NASA
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Presented by Witness

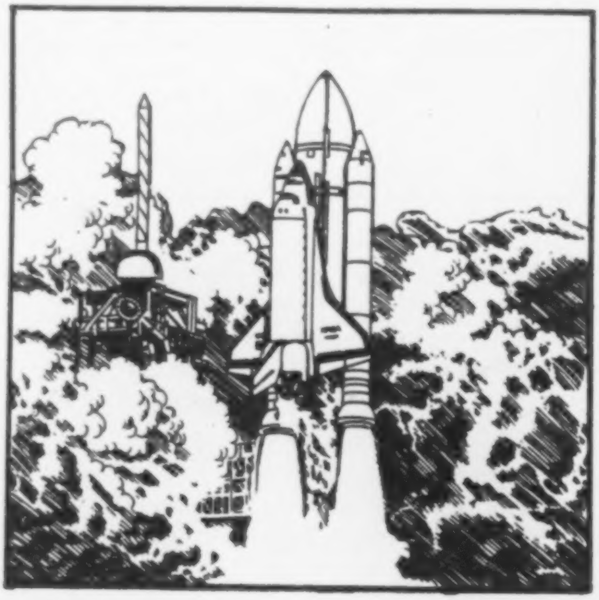
April 29, 1987

Subcommittee on Space Science and Applications

Committee on Science and Technology

House of Representatives

Statement by:
Norman R. Parmet
Aerospace Safety
Advisory Panel



100th Congress

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Statement of

Norman R. Parmet
Deputy Chairman
Aerospace Safety Advisory Panel

National Aeronautics and Space Administration

before the

Subcommittee on Space Science and Applications
Committee on Science, Space and Technology
House of Representatives

Mr. Chairman and Distinguished Members of the Subcomittee:

The Aerospace Safety Advisory Panel presented its annual report to the NASA Administrator and his senior managers during the Panel's statutory annual meeting. This report, which covers our work from January 1986 through February 1987, was also delivered to the Congress at that same time in early March 1987. Additional copies of this report are available along with a special "Lessons Learned" report issued in November 1986. The following taken from the annual report is background to this statement: "Panel members and consultants were involved in more than 50 individual and group factfinding sessions, congressional hearings, "one-on-one" meetings with NASA senior managers, and were (and are) participants in National Research Council independent oversight groups examining the solid rocket motor redesign, flight rate and manifests (completed), Failure Mode and Effects Analyses and critical items and hazard analyses. Panel information, oral and written, was supplied to the Presidential Commission on the Space Shuttle Challenger Accident and the House Committee on Science and Technology Investigation of the Challenger Accident. NASA's response to the Panel's last annual report (issued January 1986) is quite detailed. Due to the changes which NASA experienced in 1986, multiple response letters (from the NASA Administrator) were provided between September 1986 and February 1987 covering first the aeronautical programs, then the Space Station, and last the Space Shuttle Program. These appear in the Appendices portion of the annual report."

In consideration of the specific points to be covered in this testimony the Panel will focus on Space Shuttle recovery activities which include:

1. That which is being done well by both NASA and its contractors,
2. If improvements are needed in the recovery program, what should they be and how best to implement them,
3. What advice does the Panel have for the Congress in its oversight role which can support such improvements as noted in "2" above.

First, our general feelings about the recovery efforts up to this point in time.

A little over a year ago the national tragedy of the Challenger accident occurred. The recovery program to continue Shuttle flights is well under way--but the next flight will not occur until sometime next year--a hiatus of more than two years in Space Shuttle operations. Since early operations will clearly be of a testing and experimental nature, flight rate will not be that of a "going" program.

The absence of a clearly articulated national commitment to space development and exploration by the United States--in conjunction with the availability of alternative launch systems of other nations--has created a situation where NASA could be tempted to rush the Space Shuttle back to flight status. The need to keep the United States competitive in the international market for space flight services cannot be permitted to override a commitment to "safety first; schedule second."

NASA's recovery program including reorganization, responsibility definition, redesign efforts, testing programs, safety organization responsibility definition and analysis and redefinition of operational requirements are for the most part in place and/or on-going.

Although this work is not complete by any means it is being accomplished within the recomendations of the Presidential Commission on the Space Shuttle Challenger Accident and the House of Representatives Committee on Science and Technology investigation report on the Challenger accident, which include special panel activities of the National Research Council.

The recovery program is viewed as acceptable. However, it is important that the planned work continue to completion. The analysis, redesign, testing and other activities which have not moved out of the planning stage into the "hardware" stage should not be "short changed." Again, safety first and schedule second.

The current efforts of the Aerospace Safety Advisory Panel are to advise and assist NASA and their contractors in their efforts to finish the recovery task. This does not mean that all work reviewing the adequacy of other safety and performance improvement design changes or procedures will cease. Development and testing will always reveal that changes and improvements are desirable.

Our areas of interest can be divided into four pieces.

1. Organization and Management

2. Analyses/reviews
    a. FMEA/CIL reviews
    b. Hazard Analyses
    c. OMRSD and OMI reviews

3. Hardware and Operations
    a. SRM/SRB
    b. ET
    c. Orbiter
    d. SSME
    e. Launch Processing System
    f. Mission Control

4. Software
    a. Flight
    b. Ground

Briefly, let us look at some of those things that are going on as a part of the recovery effort as NASA and its contractors press toward a safe and successful launch and mission in 1988. Element by element we find the following:

1. Organization and Management

As a result of the Sam Phillips' committee and other studies of NASA's roles and responsibilities for the current recovery program for the Space Shuttle, establishing the Space Station Program and maintaining and upgrading the other aerospace and science activities many modifications have been and are still being made to the NASA structure and its operational modes. Here we will focus on the Space Shuttle only.

a. The establishment of the new Office of Safety, Reliability, Maintainability and Quality Assurance (SRM&QA) with an Associate Administrator at its head and corresponding changes at the NASA centers is strengthening NASA's ability to meet the challenges of returning the Space Shuttle to safe launch and mission conditions. There has been a significant increase in the personnel numbers of both civil service and support contractors, particularly at the three "manned space centers" and headquarters. A change in operational conditions is likely to lead to problems of defining the workload, roles and responsibilities. Asserting leadership to obtain a coordinated and integrated approach to SRM&QA is a delicate process. The dedication of the safety, reliability, maintainability, and quality assurance people is unquestioned. The level of the safety, reliability, maintainability and quality assurance organizations at JSC, MSFC, and KSC are such that both the Center directors and the program/project managers are being kept well informed.

b. The Panel also cautions against placing excessive reliance upon the shoulders of the SRM&QA organization. Remember, hardware and software quality and safety must be "built-in" from the start.

c. Priority objectives of the new management team must be to enforce NASA's management instructions by defining clearly the responsibilities and authority of the NASA centers and managers. A willingness of all NASA centers to pull together is crucial if the Space Shuttle program is to succeed. Last, the Panel finds that recent reorganization of Space Shuttle management is a positive step in the direction of recapturing the spirit of mutual respect and trust at all levels.

d. NASA and Shuttle Processing Contractor managers are communicating reasonably well. However, there is a continuing need for such communications with the "hands-on" workers involved in the launch processing to assure that there is a clear sense of mission and direction, and to benefit from employee initiatives and suggestions during these crucial months prior to the flight of STS-26.

e. NASA now recognizes that the Space Shuttle is a system with both developmental and operational characteristics. Further, there is a full understanding that to emphasize one characteristic at the expense of the other is likely to result in missing key elements of the Space Shuttle management challenge.

f. The Panel has noted that a concerted push to achieve greater consolidation and upgrading of STS information systems (data bases and their utilization) is in process. This is important in that it uses critical resources more efficiently and effectively, and provides for better program risk management. In line with this, the System Integrity Assurance Program Plan, which responds to the Presidential Commission Recommendation IX, is in development. In addition, NASA is considering establishment of the Shuttle Processing Data Management System that is intended to tie together numerous data bases. This should result in a more orderly and timely safety approach to mission success.

g. The Shuttle Processing Contractor is expanding training opportunities for workers in a manner which is now focusing on meeting the needs of the individual workers, expanding worker skills thereby permitting longer term career progression and reulting in greater motivation.

2. Analyses and Reviews

As a result of the many recommendations made by both external and internal groups NASA has instituted a wide variety of new or expanded analyses and reviews in support of the Space Shuttle recovery effort, e.g., Failure Mode and Effects Analyses and

Critical items, hazard analyses, Operational Maintenance Requirements and Specification Documents and their associated Operation and Maintenance Instructions (procedures), Safety/Reliability/Maintenance and Quality Assurance related documentation and reports, test programs, qualification and checkout programs, etc. As a matter of fact, the scale of resources required for these endeavors are severely taxing. It is difficult to maintain oversight of such a multitude of activities with limited experienced personnel and time. Often one finds that the expertise required to examine and revalidate an Failure Mode Effects and Analysis, for example, on an Orbiter Reaction Control System demands the attention of the same people reviewing the auxiliary power unit and other propulsion subsystems. Thus many items must be done serially rather than in parallel.

The Aerospace Safety Advisory Panel has members assigned to and participating with the National Research Council special Panels. For example:

- Melvin Stone has been working with the NRC Panel for the Technical Evaluation of the Redesign of the Space Shuttle Solid Rocket Booster.

- Norman Parmet and Gerard Elverum are members of the NRC Shuttle Criticality Review and Hazard Analysis Audit Committee.

- Norman R. Parmet was a member of the NRC ad hoc panel on Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization.

It is interesting to note that a number of "ex-panel" members are also involved.

In addition, the Panel members have participated or are participating in other special ad hoc review teams such as the one on the Solid Rocket Booster Aft Skirt Structural Reassessment. In support of these activities the Panel Staff Director maintains a continuing knowledge of both external and internal NASA and contractor actions associated with Space Shuttle recovery plans, their implementation, and day to day program and project activities.

Based on these relationships and individual and collective efforts, the Panel notes the following with regard to recovery analyses and reviews:

a. Restoration of public confidence in NASA's ability to manage effectively the Shuttle program is crucial to success and requires NASA's leadership to keep in perspective the activities of the many advisory groups, task forces, and panels that have been created in the aftermath of the Challenger accident. NASA has the ultimate responsibility and authority to manage the National Space Transportation System after giving appropriate consideration to the findings and recommendations of oversight groups. The individuals involved in these review panels, as well as Members of Congress, must recognize that excessive reliance by NASA management on external and internal review groups runs the real risk of destroying NASA's initiative and self-confidence which are key elements of success in any human endeavor.

b. Direction of the analyses and review activities (and all others associated with the recovery plan) are assigned to the Program Manager of the National Space Transportation System, Arnold Aldrich and his technical management team. Separate, but mutually supporting, are the activities of the new Safety, Reliability, Maintainability and Quality Assurance Associate Administrator's office under the direction of George Rodney. The NASA Headquarters and Center SRM&QA personnel are an integral part of the working teams on SRB redesign, FMEA/CIL reviews, Hazard Analyses updates, the development of Non-Destructive

Evaluation and methodology. On the whole these people provide a much needed check and balance on the entire Space Shuttle recovery review and analyses effort.

c. A series of reviews of the KSC processing paperwork for the Space Shuttle have been conducted by the Aerospace Safety Advisory Panel, the NASA Shuttle Processing Contract Review Team, the Paperwork and Preparedness Review Teams established by the current KSC Director, and others. In summary the paperwork systems at KSC require upgrading to assure that documents are current, easy to understand and easy to use.

d. In general the Aerospace Safety Advisory Panel agrees with the assessments made by the NRC Panels to date regarding the flight rate and manifests, the FMEA/CIL and hazards, and SRB/SRM redesign and reverification. However, there are some areas that need further understanding and/or clarification. For example, the NRC states that:

- Criticality 1 and 1R items should be assigned priorities based on the probability of occurrence.

- Since many of the Criticality 1 and 1R items differ substantially in terms of the probability of failure, NASA should consider modifying the definition of critical items to account for these differences.

In the troublesome arena of probabilistic risk assessment which includes determining, insofar as possible, the probability of failure or success of a component, subsystem and/or system, the following guidelines are derived from Dr. Harold W. Lewis:

o Don't use probabilistic risk assessment (PRA) as a bottom line for the risk of a launch. That is its weakest use, because of the large uncertainties, and is of little help to a decision maker. In addition, practitioners of the art are addicted to

a. Solid Rocket Motor/Booster

There is little that we can add to the reports and documents issued on the subject of the SRB redesign, tests, certification and handling. However, we would make the following observations:

(1) The Panel finds that NASA is proceeding with a redesign of the SRB joints that uses existing steel cases and forgings. The redesign is a marked improvement over the original joint design but may have a problem with mating, demating, and re-use. The approach selected entails more risk of not being able to achieve design objectives than would one using new forgings that might permit a more sophisticated design but which would delay the first shuttle flight for 3 to 5 years. Proof of adequacy of the redesign depends strongly on satisfactory results from a thorough test program. The Panel agrees that the case field joint and nozzle-to-case joint redesigns (and their parallel and alternate designs) along with a thorough and rigorous quaification test program can result in a safe structure.

(2) It is the opinion of many experts in solid rocket motor design that the number of tests in the preliminary test program is minimal for the scope of the redesign. Any further reduction in the test program could be hazardous and is not recommended. The Panel recognizes that there is no way to guarantee that any number of tests can ensure that all possible operating and loading conditions and assembly differences can be encompassed by a finite test program.

(3) The Panel recommends that a more complete definition of the certification test program be required in order to determine its adequacy. The Panel also recommends that a concerted effort be made to include additional full-scale

hot-firing tests in the final test program plan so as to reduce the possibility of undiscovered weaknesses. Further that during the first year of resumed Shuttle flights, the SRBs be heavily instrumented to obtain both structural and performance data and that these data be considered as part of the certification program.

(4) To attain a SRB design with a higher margin of safety for the long-term use with the Shuttle, it is suggested that NASA proceed with the development of the "Langley" design (or its equivalent) for the case field joint and the "Hercules" design (or its equivalent) for the nozzle-to-case joint in an aggressive effort.

b. External Tank

As with the other parts of the Space Shuttle, the External Tank is being reviewed to assure nothing has been dropped through the crack. The ET/SRB attachment ring, the ice accretion (if any) interaction, the fuel pressurization system interface with the Orbiter, etc. are all areas of interest. Waivers to specifications are being handled in the same manner as the remainder of the stack. The Panel has not seen anything to date to single out at this time.

c. Orbiter

From the viewpoint of mandatory modifications to be made prior to the STS-26 first reflight and reverification of subsystem integrity after a non-flight status of more than two years there are a number of points to be made:

(1) The Orbiter contains the major portion of the Main Propulsion System, the controls, supply lines for liquid hydrogen and liquid oxygen, SSME's, 17-inch disconnect valves, and pressurization control system. The Panel has

recomended a flight readiness firing (FRF) be performed to assure integrity, operational performance, measurement of twang to set SRB firing timing, exercise of launch control center and its personnel, and abort shut-down. The FRF was recently approved by NASA.

(2) Structural loads and resultant structural stress conditions continue to crop up as a concern, particularly the mid-fuselage area and portions of the wing. This concern centers on the accuracy of the analyses associated with the 6.0 loads cycle and the measurement of actual loads and the structure's reaction during ascent and descent flight. The Panel will continue to follow this.

(3) Landing gear subsystem and nose-wheel steering are two areas subjected to examination by the Panel for a number of years. The Presidential Commission commented on these as well. This was also discussed in some detail in the NASA response to the recommendations of the House report of the investigation of the Challenger accident. It appears that management attention has been focused on these areas. Of particular note is the decision to make the nose-wheel steering fail/op-fail/safe, and the large increase in energy absorption capability of the enhanced brakes.

(4) Line Replaceable Units (LRU's) pose a unique problem in that suppliers of such items are feeling the "crunch" of the Shuttle flight hiatus just as NASA and the prime contractors are. The concern here is several-fold: ability to replace and/or repair aging LRU's, assurance of configuration control and currency of engineering drawings, applicability of ground support equipment and test and/or checkout units. NASA and its primes are aware of these possible problems and the SRM&QA

organizations are focusing additional attention on the significant items. Extra effort has also been made in improving and maintaining communications among suppliers, Shuttle Processing Contractor, Rockwell and NASA.

d. Space Shuttle Main Engines (SSME)

Early testing at Full Power Level (FPL-109% of Rated Thrust) showed that margins were inadequate for operation at that thrust level. As a result, a three phase improvement program was undertaken with the objective of developing an engine suitable for operation at FPL at the end of Phase II and one with enhanced margin at FPL at the end of Phase III. The program was modified subsequently because of funding restrictions to two phases (with a somewhat less comprehensive Phase II) and with Phase III reduced to a technology development program called the "Precursor Program." At the time of the 51-L accident, the Phase II engine was about half way through its certification program for operation at FPL.

An extensive re-examination of the design and test history of the SSME was conducted during 1986 and into 1987. The objective of the effort was to identify any safety issues that might have been overlooked in the past and to establish and validate an engine configuration for use in the next series of flights.

The engines planned for the next series of flights will basically be the Phase II engine configuration that was being certified for flight for operation at 109-percent rated thrust during 1985 and 1986. These engines incorporate many of the improved cycle life turbopump components developed as part of the Phase I improvement program described in the Panel's 1984 and 1985 reports. During the testing in this program several additional issues arose and design modifications to resolve them will be incorporated in the "first flight" engines.

The results of the FMEA re-visit identified a number of areas where changes in hardware, software, redlines, or inspection criteria could reduce the probability of certain failure modes. Such changes will be incorporated in the engines. In the Fall of 1986, 25 such items had been identified. Of these, the more significant ones requiring resolution before flight are high-pressure turbopump blade cracks, high pressure fuel turbopump coolant liner buckling, main combustion chamber coolant outlet neck cracks, and 4000 Hz vibration phenomenon in the thrust-cone region.

Another issue relating to contact line temperature on the main bearing balls in the High Presure Oxygen Turbopump is also receiving much attention.

The engine contractor is making considerable progress in developing a more useful risk assessment and margin validation methodology. This should result in an improved understanding of the safe operating regime of the engine and better control of the critical aspects of the engine configuration.

The Panel was disappointed to find that work on the precursor (improved margin) engine hardware is still proceeding very slowly because of limited funds and lack of test stand availability.

The changes described above primarily address hardware reliability, firmer redlines, configuration control and improved hardware cycle life. In only a few instances will there be any significant improvement in margin to failure. The Panel recommends, therefore, that the Phase II engines be constrained to operate at 104-percent rated thrust or less, except under emergency conditions. Furthermore, it must be noted that a significant increase in operating margin of safety can be achieved by operating at 100-percent rated thrust. It would be prudent, therefore, to operate at 100-percent thrust where possible until the Phase II engines have accumulated significant flight operating time so as to provide a meaningful data base.

It is also recommended that NASA and its SSME contractor continue the development of improved methods for actually demonstrating critical operating failure mode margins and the more rigorous risk assessment analytical procedures. It is suggested that, as part of such procedure, the term "Failure" be defined as a violation of any of the governing design criteria for a component rather than as an event such as structural failure or burn-through. By way of illustration, crack growth to the point where a calculated stress margin falls below 1.4X should be called a "failure" rather than when it reaches the "rupture critical flaw size."

e. Launch Processing System (Launch and Landing)

Preparation of the Space Shuttle for flight and the launch of a mission revolve around the KSC operations. These activities include NASA centers, JSC and MSFC, and various support and development contractors. The principal contractor is the Lockheed Space Operations Co., the Shuttle Processing Contractor (SPC). In the course of our reviews, we drew information from a variety of sources at KSC including face-to-face discussions with more than 40 "hands-on" technicians, quality control inspectors, and schedulers. This was in addition to discussions with senior and mid-level managers from both NASA and SPC.

There is a high level of activity at KSC to bring its facilities to a state of readiness that will adequately support not only the initial reflight but subsequent missions. These tasks must be coordinated with the extensive procedural reviews, hardware upgrading and modification, software changes, and other recovery efforts. In the Panel's opinion, and in line with our earlier admonition of "safety first; schedule second," the remaining burden of the work makes the goal of launching STS-26 in early 1988 highly improbable. At this juncture it is even extremely difficult to set forth with precision the full work load facing NASA and the SPC prior to the initial reflight. The Panel wishes to underscore the importance of developing the attitudes, systems and procedures that will support a safe launch processing environment long after the attention and notoriety of STS-26 has faded.

In response to concerns raised by the Presidential Commission and reflecting concerns voiced earlier by the Panel, NASA established a review team to examine and assess implementation of the Shuttle Processing Contract at KSC. This team gave particular attention to the relationship between the activities of the SPC and the expertise associated with flight hardware contractors. It is essential that persons most knowledgeable about flight hardware systems participate in launch processing. The Panel believes that those elements of sustaining engineering that require detailed knowledge of the design and development history of airborne hardware should remain with the design centers and their contractors. The current contractor arrangements appear to be working reasonably well.

There are policies and activities associated with launch processing where achievement of more routine and predictable operations would enhance safety and reliability. For example a freeze should be declared on non-mandatory changes during this period before STS-26 launch, combining and/or coordinating the many data systems which support launch processing at KSC, and adhering to a launch schedule that best fits the hardware redesign and reverification programs now underway.

f. Mission Control/Flight Operations

Included in mission control and flight operations are flight and ground crew training, mission control center operations, flight operations planning, mission analysis, post flight anomaly resolution, inflight payload control and operation. Recently a consolidated operations contract covering most of the operations at JSC has been completed with Rockwell International. However, this "new" contractor has not had to live through an actual mission, and sufficient attention must be given to bringing this organization up to a point which can assure a safe level of support for STS-26.

The announced policy of the Administration to launch payloads not requiring man's presence primarily with expendable launch vehicles (ELV's) should relieve the pressure on NASA to accelerate Space Shuttle flight rates to a number that might severely tax the agency's resources and perhaps reintroduce unwise and unsafe operational practices. Nevertheless, it should be recognized that should the Space Shuttle eventually attain annual launch rates of 12-16 it could become one of the more economical launch systems.

g. Non-Destructive Evaluation/Testing (NDE/NDT)

The Space Shuttle is, of course, a complex arrangement of components, subsystems and systems that must be very carefully assembled to perform all the critical functions necessary for mission success. Examples include the Solid Rocket Motor joints, welds and some composite material assemblies. It has become increasingly obvious that current non-destructive testing methods are not adequate to do the job as effectively as desired to evaluate the "goodness" of those assemblies that cannot be visually inspected. The Panel supports NASA's continuing efforts to develop and use more effective NDE/NDT methods to assess the quality of "as-built" hardware prior to the next launch. Improved techniques in this area will increase the likelihood that handling and assembly defects will be identified and replaced or repaired prior to installation or use.

4. Computers and Software

Fundamental to the safe operation of both flight and ground Space Shuttle systems are the computer hardware and software. For the next several missions the current hardware will be used. This requires the careful attention which has been the hallmark of such Orbiter and launch support activities to date. Further, there are no hardware modifications under consideration for the STS-26 mission so that the Panel's attention has been directed to the software assurance efforts of NASA and its contractors. The SRM&QA personnel are participating in software actions associated with acceptance, verification, and configuration. Such activities will go far in alleviating the Panel's concerns as noted in its annual report:

a. The methods of determining and validating the 8,000 or so I-LOADS that must be defined for each Shuttle flight. These constants define the mission to be flown and are as important as the software and computers to the success of a mission.

b. The methods by which software tests are generated. The quality of the resulting software is highly dependent upon these procedures.

c. The methods by which compiler upgrades are tested. The compilers translate the program written for the Shuttle into the code executed by the computers.

d. Redundancy management among the computers, in particular, timing and comparison methods.

In addition to these technical concerns, there are several concerns about personnel matters:

a. It appears that in order to progress in terms of salary, NASA people must move into management ranks, making it difficult to keep experienced, highly qualified people in the purely technical ranks. Moreover, it appears that the salaries of NASA technical people are substantially below corresponding industry salaries.

b. Much of the knowledge of Shuttle computer development and operation resides in the corporate memories of the employees who have worked on the system. The age distribution of the employees working on the computer system appears to be heavily skewed toward the older age groups and that there is a dearth of employees in the mid-age group.

5. Crew Escape

Crew and/or Orbiter recovery during first stage ascent has relied exclusively on additional landing sites based on the premise that multi-fault tolerant design features in the solid rocket motors, the Space Shuttle Main Engines, External Tank, and Orbiter systems would permit the implementation of this abort option. The Challenger accident has resulted in a reconsideration of this philosophy albeit not simple alternatives exist, especially for a two-engine-out emergency. Recent studies by NASA and its contractors, have introduced the possibility of crew escape from the Orbiter during controlled gliding flight through the side hatch employing a tractor rocket arrangement. Prime safety concerns with this system are the presence of pyrotechnic devices in the crew compartment, the extraction sequence, the attendant personnel protection system, and survival after splashdown. Nevertheless, the principal attraction of this type of system is the avoidance of Orbiting ditching--an almost certain catastrophic event. Despite the inherent risks of such a system the Panel believes it is worthy of continued study and possible Space Shuttle use.

The Panel has several concluding observations on related issues that can affect safety, directly or indirectly:

The dangers involved in initiating and sustaining a high-tech, high-cost development program in a political environment where each annual budget is a life-or-death proposition are real. The temptations toward exaggerating the benefits and understating the costs and problems are great.

This problem of "truth-in-budgeting" compounded when officials and managers actually begin to believe their own "sales" rhetoric. Technological reality that conflicts with the political rationale is kept at arms length. In addition, as resources and schedules are stretched, individual managers often focus on keeping their small part of the program alive. Fewer and fewer persons pay attention to the larger stakes, the bigger picture.

People assume that problems will make their way up the bureaucratic chain-of-command. That often doesn't happen. A bureaucracy instinctively avoids passing along bad news. Accountability is allowed to become unclear and diffused. External political and budgetary pressures eventually wear down good judgment and common sense. These many factors eat away at the good management practices, traditions, and structures.

Finally, there is always the danger of oversight gridlock--the situation where institutionalized second-guessing through myriad review panels, oversight committees, investigative bodies, and the like dilute the sense of responsibility, discipline, and accountability that properly resides with line managers. Safety is principally the result of disciplined, careful design, systematic testing and evaluation of the designs, faithful construction or manufacture, full knowledge of the system's strengths and weaknesses, and the discipline and dedicated performance of people.

The danger in placing undue reliance on an elaborate structure of review and oversight groups is that it can become a justification for not doing the job correctly in the first place. "Not to worry," says the manager to himself, "the reliability and quality assurance guys down the line will catch it."

Mr. Chairman, on behalf of all the Aerospace Safety Advisory Panel members and consultants, I would like to thank you for the support we have received from this subcommittee. It has been our pleasure to be another set of "eyes" and "ears" for you in assuring that things prudent and reasonable are being done to make the first reflight of the Space Shuttle, STS-26, both safe and successful.

Mr. VOLKMER. Thank you very much, Mr. Parmet. I'm sure that you are going to be able to field the questions very adequately. I still have some, though.

As I finished up with the General, and as I note during your presentation, you state that you support that type of risk assessment. Did you mention that as what, problematic?

Mr. PARMET. Probabilistic.

Mr. VOLKMER. Probabilistic.

Mr. PARMET. I find it hard to pronounce. Probabilistic risk assessment.

Mr. VOLKMER. And basically based on technical engineering, basically. In other words, the statistical data is part of it and everything, but what I am getting at here—and I didn't ask General Slay that, even though he was there. I might still; I doubt if I am here when he gets back, because I am going to have to leave, but I will ask you this question: All engineers don't agree on everything, do they?

Mr. PARMET. That's true.

Mr. VOLKMER. When you get into a judgment call, and that's what we are calling here, a judgment call.

Mr. PARMET. How do you think I got this black eye? [Laughter.]

Mr. VOLKMER. Now what I am getting at, are we then going to end up with statistics and say, "Well, we've got four here," or are we going to have one person make that decision ultimately? Are we going to say, "There's four that have looked at it. Three out of the four think it's okay to go ahead without further changes," or "We have made these changes and they think these are satisfactory. One dissents," and then shove it up to somebody else to make the final decision on that?

Mr. PARMET. Well, nothing is simple and as straightforward as that. It is not a voting process in that sense. You have all these tools—FMEA and hazard analysis and engineering judgment, engineering design. The capability is there. The people who have designed this system know the most about it.

Now if you add to that a vehicle that can help place some of the major decisions that have to be made in perspective, one with respect to another, use whatever tools appear to be helpful to you. While we talk about statistical analysis, what we mean is likelihood, and I have heard people argue that you shouldn't even use the word "likelihood," likelihood of failure.

The wing on a commercial airplane is not very likely to fall off, and the probability of its failure might be 1 in 10 billion, but to have an engine failure in flight might be 1 in 1,000 hours of operation. You would focus your attention first on an engine failure and try to correct those conditions, than you would spend time on the wing structure which is already damn good, even though each are criticality 1 items, if we may use that terminology.

So all we do is, we don't play numerical games. We try to say, "Hey, one is more important from a priority standpoint than the other one." Does that respond to——

Mr. VOLKMER. I think so. In other words, what you are really telling me also is that you're looking at ways to improve whatever has that criticality 1, if it can be improved, and some things cannot, and those that need improvement or greater need improvement would be looked at first to make that improvement.

Mr. **Parmet**. That's right.

Mr. **Volkmer**. You're talking about, I know that like on the main engines, the SSME's, that there is always a constant movement, like in the pump and then some of the valves and stuff, to make those corrections or to make them better, so that they work at higher temperatures or at more turnaround uses. That's what you're basically talking about. We're not looking at ways to make better improvements on the attachment where the wing attached onto the fuselage, or——

Mr. **Parmet**. Unless the wing/fuselage design is lousy, you wouldn't.

Mr. **Volkmer**. You wouldn't do that.

Mr. **Parmet**. You wouldn't look there, because you would think that would be very early attacked and done well.

Mr. **Volkmer**. All right, but if in the future we would say, "Well, we're going to have to change, let's say, the degree of the wing as to the body," at that time you would look at what stress, et cetera, that would put on it.

Mr. **Parmet**. Well, some of the test programs, as a matter of fact, have revealed there are some weaknesses in certain areas because of heat leakage, and there are some structural design improvements, that are going to be required because of that.

Mr. **Volkmer**. Okay. Now on the SRB's you mentioned that you looked at and the field joints are better than what we had before, my question is, are they the best?

Mr. **Parmet**. Well, let me first tell you——

Mr. **Volkmer**. I mean, there is improvement. Is it improved as far as it can be improved?

Mr. **Parmet**. You can always improve more. I would like to turn to Mel Stone here and let Mel respond to it. He is on the NRC panel, and he is our structural expert in that area.

Mr. **Volkmer**. Okay.

Mr. **Stone**. Well, to try to answer your question, the first portion of it is that it is a marked improvement. As far as the field joint is concerned, the rotation in the field joint at the tang to actual clevis, the rotation was about 45 mils. With the capture feature now it has been reduced to like .009 or actually 9 mils. That is a marked improvement.

If you look at the nozzle-to-case at the aft end, that also, the rotation and the separation was approximately the same, about 45 mils, and that has been reduced down to, I believe, 7 to 9 miles, so from that point of view those two joints are what I call a marked improvement. Obviously you can get it better by not having any rotation whatsoever. I think that if we did that, the design would probably—oh, may be available in maybe 3 or possibly 5 years, because that is really a different, sophisticated design that you need a lot of testing, designs and really a lot of information goes in before you come up with that specific design, so your first answer, yes, it definitely a marked improvement.

Mr. **Volkmer**. All right, but not necessarily the best because we don't know for sure what the best is.

Mr. STONE. Even if I would say that I know a better way to do it, more sophisticated and everything else, you have to go through the whole test procedure and after you're finished with that, there's a question whether or not there aren't some fundamental problems there that will be eked out by the test itself. So even though you can think that you may have a more sophisticated design with a higher margin of safety, it may not be.

Mr. VOLKMER. The other question I had in regard to that, as I sit here, with the new design, is that going to impact on—down at the Cape when they start putting them together, you know, they get out of round. When they hit the water and we re-use them, they are not necessarily in quite 100 percent degree as to roundness, both of them fitting each other. Now we've got this tang going down this way. How is that going to impact on that?

Mr. STONE. I understand your question and I think it's something that we're concerned about also. As far as safety of first flight, I don't think there is a problem, mainly because of the fact that you're not talking about reusability at that specific time. But yes, we think that there is a concern that we have on assembly, reassembly, re-use, corrosion and many other aspects of it.

Now a number of tests are being made at this particular time, assembly-type tests for mating and demating, and these tests actually will be conducted at a future date. We have a schedule we're working to. However, the re-use part of it, what we have suggested that they do is to go back and look at the history of the actual water-impact landings that have taken place, note where corrosion has taken place, and try to make some kind of a correlation between what happened there and what could happen. Now obviously, until you re-use that particular vehicle there could be a concern.

Mr. VOLKMER. Okay. Thank you.

Mr. Parmet, you also mentioned that you had looked at, or maybe one of your panel had, as far as the Research Council deliberations or committee work, the safety and numerical use of the shuttle in future years. I can remember back when we were talking, with four shuttles we were going to do 24 a year. Now would you at this time in hindsight—and I know what my answer to my own question would be—but in hindsight say perhaps that was a little overambitious, knowing everything we know today?

Mr. PARMET. What do they say? "A man's reach can exceed his grasp, or what's a heaven for." But this reach was way the heck out beyond anybody's grasp.

I was on Ed David's panel and he will testify before your committee tomorrow. We came to the conclusion that a flight rate of about 12 a year was all one could reasonably expect out of the NASA program. It's not just having four shuttles. You would have to have a fourth one to get a rate of 12 a year.

Mr. VOLKMER. Would you tell me that again? Repeat that.

Mr. PARMET. First of all, I don't think you can get 12 flights a year if you only had three shuttles, because in effect there are so many unknowns that we felt that one of the three vehicles will almost always be out of action for some kind of maintainability reason or other modification or repairs. To get 12 flights a year out of three would not be very likely. They would have to do a lot of things differently and they would have to get a lot more under their belt.

We don't think that is feasible in the 1992 time period, and with the fourth one underway and joining the fleet, let's say, in 1991 or 1992, we think 12 flights a year is reasonable to achieve. We felt for short bursts, say in a three- or four-month time period, you could get a rate up to where NASA says, 15 or 16, but we don't feel you could sustain that rate. More people are needed in both the operational end of NASA and in the technical end of it.

We don't yet know the total consequences of all the maintainability and maintenance requirements that will be placed on the shuttle, all the inspections that will be placed on it in order for it to be ready for the next flight. They are still being developed, but I personally believe it will do nothing more than extend the time between flights. That among other reasons is why I feel that 12 flights a year is about all we are going to attain in the 1992-1993 time period.

Mr. **Volkmer**. Then in 1988, 1989 and 1990 and 1991 we are looking, if I use mathematics, simple mathematics, three a year, even possibly we could—I mean per shuttle—we could even be less than nine with three.

Mr. **Parmet**. Oh, yes. I think first of all any start-up year, everybody is going to walk like they are walking on eggshells. In the first year probably three or four flights are about all they are going to get off, and they will gradually build to, let's say, the full capability of flight rate across a four- to five-year period, and then it will level off. After that you may begin to increase the rate slowly as NASA finds ways and means of handling the shuttle better than they do now. New designs make it more reliable; the engines stay together better; the solid rocket boosters perform perfectly; everything falls in place, down the line maybe it will get better than 12, but I don't see it in the foreseeable future.

Mr. **Volkmer**. Well, I'm saying we are going to have only three for a while.

Mr. **Parmet**. Then you're not going to get——

Mr. **Volkmer**. That's a foregone conclusion. I mean, you can't build that fourth one overnight, you know. We're not working with tinker toys.

Mr. **Parmet**. If you had four today it wouldn't make any difference. In my view you would still build up very slowly because after this accident, everybody is going to start treating this as an experimental and development program once again until everybody is sure of the direction they're heading, and then they will build up the rate again. We're back to flight testing, in effect.

Mr. **Volkmer**. Well, what you're telling me, though, is that by 1990 and even 1991, and even when we get the fourth one in 1992, because it is going to have to go through development, we're looking at the maximum of nine flights a year until we get the fourth on.

Mr. **Parmet**. Well, when you get—that's about right.

Mr. **Volkmer**. Okay. Then there's no question in my mind that we should be taking—and I'm talking about we in the Congress if at all possible—means to fund ELV's, unless we want somebody else to do it for us.

Mr. PARMET. That's one piece of it. I think ELV's are justified for more than just that one reason. If you look at future projects of NASA and the Federal Government and the Air Force and "Star Wars," if you want to throw that in there, there is a heck of a demand for putting payloads of some type in space. Some of it needs to go by means of a manned vehicle.

My understanding of the last presentation I heard on the Space Station was, they are going to need 40 flights across 4 years. If that is the case, you couldn't rely on the shuttle because this would take more flights than the shuttle was capable of producing. For this reason, if for no other reason than that, we feel that the ELV's should come into the picture, especially if you can develop a system where you can put heavy payloads into orbit, say 100,000 pounds into orbit without manned flight doing that, and then send the shuttle up there with people and the stuff that needs people so that a Space Station can be assembled.

So yes, we say there ought to be the development of ELV's and we think there ought to be new heavy payload vehicles included.

Mr. VOLKMER. I want to thank you for your answers. I'm sorry—it is most informative—but I have to leave. I have another meeting to go to. It's one of those times. Thank you very much.

Mr. PARMET. Thank you.

Mr. NELSON. General Slay, could you come up? I understand that you've got a plane to catch, and let me get some of these questions.

The rest of the panel members can just stay right there because we're going to get back to you. Let me just ask these questions to General Slay and then we can resume.

I want to ask you about the SR/QA. Do you think the organizational and procedural changes that NASA is making in these areas of safety and reliability and quality assurance, are they adequate?

General SLAY. Well, Mr. Chairman, only time will tell whether they are adequate or not. I will say this without any reservation: It is certainly a move in the right direction. I think that from what I understand of NASA's history, we have had a sort of a dip over the past few years in this area of disciplines, and with the establishment of George Rodney's office at the associate administrator level, I think it gives a lot of visibility to these kinds of things. I strongly applaud NASA for doing that, but whether or not it turns out to be organizationally adequate, only time will tell.

Mr. NELSON. All right. Let's talk about spare parts. How can we be assured that NASA's approach to the problem of spare parts and former cannibalization, how can we be assured that this is adequate?

General SLAY. Well, obviously the best way to avoid cannibalization is to provide more money for spare parts. I am diametrically opposed to cannibalization except in an extremely urgent situation. There is nothing good about cannibalization. It is wasteful of money, it is wasteful of effort, and it also introduces potential problems and potential failures just by the fact that you have an intrusion into a system to take a line replaceable unit out. So whatever is required, Mr. Chairman, I think that NASA and Congress ought to see to—Congress in providing the funds for spare parts.

Mr. NELSON. Do you think NASA's present method of contracting gives enough incentives for quality and safety?

General SLAY. I really haven't looked at that, Mr. Chairman. I couldn't say. I believe that profit levels are high enough that incentives ought to be there, but whether they are, I don't know. I couldn't intelligently answer that question.

Mr. NELSON. Do you think the current testing and certification procedures now being employed, are they adequate to ensure the safe operation of flight hardware?

General SLAY. I don't like that word "ensure." Having been a pilot for 44 years, it is very difficult to ensure that anything is going to come back on the ground in one piece. You can do everything you can to attempt to reach that mecca, but I think we'll be making a mistake if we use that word "ensure." I personally don't like it.

I think that what NASA is doing, from my point of vantage they are all doing the right things. They are going about the recertification and the revalidation in the proper way, with the few concerns that I have already mentioned to you in the area of looking at the shuttle as an overall system in the failure modes and effects and analysis area.

Mr. NELSON. Earlier we talked about the fix for the SRB's.

General SLAY. Yes.

Mr. NELSON. One of the proposals in front of this committee would be a dual sourcing for those SRB's until you got to the advanced solid rocket motor. Do you have a comment on that?

General SLAY. Well, if you could get—again I am speaking like a businessman, worrying about where the money for that would come from—that is not an inexpensive thing, to qualify a second source. If we could find a contractor willing to qualify itself as a second source and willing to compete, I think that would be great, but with the number of SRM's that we would be using, it would have to be a cost-benefit trade analysis to see whether that would be worthwhile if the Government had to fund that, and I would rather doubt that you could find a contractor willing to fund it himself.

I personally like the thought of having some competition. I am just, I think, practical enough to worry: Is this a reasonable thing to do from a fiscal point of view? I am answering this as a private citizen and not as chairman of the committee, because we have not looked at that.

Mr. NELSON. All right. As chairman of the committee, you would have observed on the question of safety whether or not any changes in the attitude toward safety in the personnel, whether they be in NASA or in the contractors. Do you want to share with us any conclusions?

General SLAY. Oh, yes, indeed. I think safety is right at the top of their "must do" list. I have met no one in NASA that would admit or even hint that safety is not going to be the paramount consideration, so I have nothing but good words to say about that.

Mr. NELSON. Do you have anything you want to share with us about crew escape?

General SLAY. Well, again, I love crew escape. You know, I have flown a lot of things where crew escape at different times was going to be a problem if I ever had to contemplate that, but on shuttle I think everyone understood at the time that we started it that crew escape would not be provided. We have all had programs in the past where crew escape obviously was going to be a difficult thing to contemplate and a very expensive thing to contemplate.

I will say this, Mr. Chairman, without any fear of being wrong: that every astronaut that ever intends to fly on shuttle would like there to be some sort of crew escape. If he doesn't, you know, I would doubt his sanity. However, if it is going to break the back of shuttle from a financial point of view, I think I would also speak for every astronaut. They wouldn't want us to break the back of shuttle.

Now if that is straddling the fence, so be it. I do want us to consider crew escape but the question is, as I am sure is behind your question, is it, number one, a feasible thing to do, and is it a fiscally responsible thing to do?

Mr. **Nelson**. Thank you, General. We have a vote in progress that I've got to run over and catch, and I will. We will stand in recess. You please go on to your commitment, General, and I will resume with the panel.

General **Slay**. Thank you, Mr. Chairman.

Mr. **Nelson**. Thank you.

[Recess taken.]

Mr. **Nelson**. We appreciate your patience. It was a close vote, 218 to 214. The Gephardt amendment prevailed, and so there was high drama on the floor of the House of Representatives. [Laughter.]

I apologize that you all have had to wait, but such is the business of the House.

Mr. **Parmet**. That's part of the game.

Mr. **Nelson**. Yes, sir.

In your annual report of your advisory panel, you had a number of very interesting statements and conclusions. Let me just get you to reflect upon them. For example, "The NASA centers must subordinate parochial interest and develop a willingness to pull together." Why don't you talk to us about that?

Mr. **Parmet**. Well, when we wrote that was late last year our view was this: that as we went out into the field and had been going out into the field through the years, we saw what we thought were little fiefdoms out there. Rather than a big, total organization, you saw a collection of individual organizations not always working together too well.

We see a great change in the sense of awareness of responsibility and we think that things are changing now. There is far more cooperation between and among centers. There is far more willingness to listen, and they are working together far better than we have ever seen them before, but the critique was made on the basis that these are things we saw and they needed to be improved, and they have been improved.

Mr. **Nelson**. And that was how recent, would you say, were those observations?

Mr. **Parmet**. Well, I guess they have been lingering observations over a number of years, and some of us felt we had to get them out on the table. We see the changes occurring mainly over the last six months.

Mr. NELSON. Okay. Another one of your statements was that the Kennedy Space Center needs adequate budgets so that they can have a sufficient inventory of spare parts.

Mr. PARMET. Yes, we said that, and carrying along the theme that General Slay responded to earlier when he was asked about logistics—if I may go back—the problem has been in the past that the money was appropriated for spare parts. It wasn't used for spare parts. It was used because NASA needed the funds for other purposes. The net result was, when it came time to fly, the only place to get replacement parts was to steal them off another shuttle— cannibalization.

There is always going to be some measure of cannibalization. I come from an industry, the airline industry, that still has some of it but not 50 percent. It's more like 3 or 4 percent where, if you're out of a part, you steal it from an airplane that is not operational. It is not a good practice, number one, because you are taking one off and putting one on twice, on two different vehicles. Every time you do something like that, you introduce the chance of error, so we don't like it from that standpoint.

I think today the funds for NASA's logistics program are in place and they are now sequestered, so that somebody else can't get their grubby hands on them. You need more than just that to maintain adequate spares, because after all there is not a bottomless pit of money available.

What you need to do with spares is, when they come off a vehicle you need to have the ability to take them, get them back to a place where they can be repaired, restored to like new, and returned and put on the shelf. Unless you do that in a reasonable period of time, you may have to order twice as many spares as you would if you had a reasonable rotation program.

NASA is well aware of its problem in this area and it is trying to attack what it calls and what we call the turnaround time. It needs more effort and perhaps even more funding. I would visualize it as having a facility right at Cape Kennedy where you can take perhaps 90 to 95 percent of those spares which could be reconditioned right at Kennedy if you had the manpower and the equipment and the facilities in place to do so, and restore them to the shelf, leaving only those parts that are very, very complex, which have to go back to the manufacturer for reconditioning, and then get on his butt to turn them as fast as possible. The combination of good sparing plus proper turnaround time, 60 days, let's say, will minimize the cost of that problem.

Mr. STEWART. Mr. Chairman, if I might just add one thought——

Mr. NELSON. Certainly.

Mr. STEWART.—about two weeks ago, and they were very candid with us to say that the repair turnaround time is getting worse, not better, so they are very concerned about that at KSC. The other thing they are concerned about, and something the committee might be interested in, is apparently in the process of building a fourth orbiter the manufacturers and NASA are eyeing the existing spare parts as going into the fourth orbiter. If that were to occur, then that would obviously exacerbate the spare part problem. although it might accelerate the fourth orbiter.

Mr. PARMET. In fact, that's a no-no.

Mr. NELSON. Well, we agree with you. It's unfortunate that people have to even look at spares to try to get their job done, but everything that you have said we certainly agree with, about those spare parts.

All right. How about your statement that top NASA and shuttle processing managers need to communicate more directly with the launch processing workers?

Mr. PARMET. Well, I am going to let others do a little talking here.

Mr. NELSON. Sure.

Mr. PARMET. Let me just introduce this by saying we had a gang of six. Six of us have gone down and we have interviewed their top people at the launch facility. We have interviewed the working guys down at the bottom of the list, and we have come to these conclusions based on the results, the feedback we got from them.

John, would you like to talk to that?

Mr. STEWART. Well, I can, just briefly. There are several others of the gang of six here who could add to it.

Quite simply, Mr. Chairman, it was a situation where in talking to the technicians who were on the floor of the OPF or the VAB or wherever, it was clear that often the communications as to what they were supposed to do on any given work assignment simply were not clear, or if they were clear, they were wrong, and so there was a lot of rework having to be done simply because the initial set of instructions was not correct. As is usually the case when you are working with—by and large, these are very qualified technicians, I mean men and women of great ability in terms of their own areas of expertise—they would have very positive suggestions to make as to how to do the job better, how to do the job easier or more efficiently. It appeared that the channels between the supervisors—the engineers employed by the shuttle processing contractor—and the workers simply were not as active as they ought to be.

I think we would say from our most recent visit and through a visit last—the end of the year, that that situation like many others is getting better, and that the SPC has recognized this is a problem and they are actively attacking it. There has been some improvement, and so the trend is in a positive direction, but you've got to keep working at it. It's very easy to let those channels clog up.

Mr. NELSON. And it's tough to make water run uphill, to get that communication going from the bottom up as opposed to the top down.

Mr. Parmet, you said earlier in your opening statement something about "oversight gridlock." Can you share with us what you meant there?

Mr. PARMET. Well, I thought I said it fairly clearly, and I am going to let my friend sitting to the right of me expand on this, but basically it seems like we're spinning our wheels quite a bit. There are so many audits and checks and double-checks and triple-checks that I think we are wasting a lot of our manpower in auditing what the guys are doing right, rather than auditing to make sure that they have the tools to do the job right.

John?

Mr. STEWART. Well, Mr. Chairman, it is the kind of statement that can be easily misunderstood. I did coin the phrase, I guess, and what I meant by that was I think what you're looking for is a kind of balance between what the line management have the responsibility for doing and the sense of self-confidence so they can do it successfully, and an appropriate level of review and audit and inspection that you obviously want to have in a program of this complexity.

In the aftermath of the *Challenger* disaster a number of oversight groups were established. As far as I can see, they have carried out their role—including our own, I might say, even though we were already there—in an appropriate way, and that right now there is by and large a pretty good balance between the line management people at NASA, who in the end have got to have the support and self-confidence to make the tough judgments that are going to have to be made, and the review groups.

So this is the cautionary note in NASA's direction, I guess, that while it is—what you want to do is consider what the groups say, weigh their suggestions, but in the end, folks you are going to have to make the tough judgments. That is the only way we are going to ever get this system up and flying in a responsible way. You can't permit review groups to kind of be a buffer for the kind of responsibility that rests ultimately with the administrator. That's all it was meant to suggest. It also applies to the Congress, too, I might say, in all honesty.

Mr. NELSON. Sure.

Mr. STEWART. The Congress has to obviously exercise an oversight role—that's its constitutional responsibility—but an appropriate oversight role, and that's something that is a judgmental question, too.

Mr. NELSON. You made another conclusion in your report. Please comment about this, and I will ask you some specific questions about it: that the shuttle should be used only where manned missions are deemed mandatory.

Mr. PARMET. Well, if you look toward the future and the requirements for payloads to be put in orbit, you see a huge amount of requirements that are built into your backlog. Some of them, such as the Space Station itself, could use up more than four years worth of full-time operation of the shuttle itself.

There has to be a balance between manned flight and other types that do not require the presence of man. Putting many of the pieces of the Space Station in orbit, for instance, could be done on unmanned vehicles, and we feel perhaps that there should be developed a heavy lift vehicle that can do that job. This is the essence of what we are trying to say. There's got to be more than one way and a more effective way. Still you will have the orbiter flying, the demand for it. Even with that constraint, only special missions, you will still have more than the orbiter can support. The backlog will still be there for many years.

Mr. NELSON. All right. Let me ask you a series of specific instances, and you tell me how your panel would respond.

What about payloads that are very expensive to convert to an ELV? Should that remain on the shuttle?

Mr. PARMET. That's a judgment call. What's the economics of it in the long run? What's "very expensive"? If it costs $200 million to convert that payload, obviously you are going to say, "Put it on the shuttle." If it's $5 million to put it on an ELV, you might tell them, "Spend the $5 million and get it on an ELV."

Mr. NELSON. All right. How about expensive payloads that need a high launch reliability? Should they be permitted to stay on the shuttle?

Mr. PARMET. Well, I think you can achieve high launch reliability with ELV's, too, so I am not sure I agree that that would be a requirement for a shuttle payload.

If any of the members of the panel want to jump in here and add a comment to that, please do.

Mr. DONLAN. I think one of the problems is, for several years now the communications people, for instance, have designed payloads in anticipation of the shuttle, and they were designed specifically for the shuttle, to take advantage of the algorithm about cost. In other words, they made pancake-type satellites which had large diameter and minimum length. There is, I know, a feeling among some that they should be allowed to at least run those out on the vehicle for which they were designed. As Mr. Parmet says, it's going to be a matter of judgment as to which of those you could profitably do that with.

There will come a time when the shuttle will get out of the R&D business and will, in fact, probably be the reliable vehicle that we originally envisioned for it, in which case there may be a resurgence of interest in using it, rather than just having it sit idle.

Mr. NELSON. Well, I am speaking of reliability in the sense that this is a man-rated system as opposed to an unmanned-rated. Anybody have any comment on that specific point? In other words, the question is, what happens if you have a payload that requires a high launch reliability? Should those be able to stay on the shuttle?

Mr. KRONE. Could I express a thought on that, Mr. Chairman?

Mr. NELSON. Please.

Mr. KRONE. It seems to me that possibly we were a little bit too rigid with that comment in this regard. Certain decisions have already been made relative to the shuttle, relative to the numbers of shuttles, relative to the resulting numbers of flights that are available for the shuttle. I think the panel would agree that it is rational to put on the shuttle as a first priority, on those numbers of flights that are available, and also considering the fact that the ELV's—there is a certain level of flights or numbers of flights that will be available for ELV's—rationality would dictate that you put on the shuttle those to that capacity that are better suited for the manned flight. If in fact you run out of those and you still have payloads to launch that aren't necessarily associated with the manned flight part of the shuttle operation, then the priorities relative to the expense and those other considerations should be considered.

Mr. NELSON. Suppose you were building another space telescope and you had the choice of taking it in the shuttle or on an ELV. What is your feeling about that?

Mr. PARMET. Well, I think we may answer your question this way. I think we believe that we would want to put such an expensive and one-of-a-kind vehicle on a manned vehicle, because if anything goes wrong at least you have a chance to correct it when you have human beings on board.

Mr. **Nelson**. Okay. How about national security payloads? If they don't need the unique capabilities of the shuttle, should they go on ELV's?

Mr. **Parmet**. Yes.

Mr. **Nelson**. And how about the space station?

Mr. **Parmet**. Well, I think there's parts of the Space Station that are going to have to go on a manned vehicle because the people to assemble the Space Station are going to need to be on the vehicle, too, so you might as well use that mission not just to bring people up to assemble it, but also to bring the pieces up, some of the pieces up that they are going to assemble. But I think for the most part if you had some kind of heavy lift vehicle you could put a lot of components in a specific orbit and then send the people up separately to assemble it, and you would be more efficient than you are with a whole series of shuttle flights.

Mr. **Nelson**. Mr. Nagle?

Mr. **Nagle**. If I could follow up the chairman's question to you, do you find in your review of NASA a willingness to consider the ELV alternative and proper planning to utilize ELV's?

Mr. **Parmet**. Well, I don't know how to answer your question. Maybe John would want——

Mr. **Stewart**. I think that it's coming slowly. I mean, NASA went through such contortions back in the seventies to get the shuttle program approved and funded initially, and all of the arrangements that were necessary finally to get the political support to go forward with the program, one of the key elements of that was they are going to be very economic, and one of the key elements in that whole analysis—and Charlie Donlan was around, and I don't know whether he agrees or not with me—one of the key elements of that was that this would be the Nation's launch system, and therefore it would be more economic.

That became kind of an article of faith, it seems to me, and I think if everything went as originally forecast back in the early seventies, it would have been very economical, but life is never as simple as that. The development process became much more complicated, much more expensive, much more difficult, but at that point NASA as an institution had a great stake in it being the Nation's launch vehicle, and so they have resisted reintroduction of ELV's because they saw it striking at the heart of the whole rationale that initially launched the shuttle, so to speak.

I think that is changing because I think that that original rationale no longer is reasonable. Common sense then eventually brings you to the point, at least from my personal view, that a mixed fleet is what you need.

Mr. **Nagle**. Well, I agree with you but I'm not sure they agree with us. That is kind of what I'm asking, and your answer was fine. I mean, I understand that they're tied to their history. The question is, how quickly can we break that umbilical link that they seem to have down there.

Mr. **Stone**. Mr. Donlan was around at the time.

Do you have any——

Mr. **Nagle**. Mr. Donlan, how do we do that? Because I think you have accurately assessed, Mr. Stewart, that they have a reluctance to make that shift.

Mr. **Stone**. Well, I think the additional factor now, of course, is the budgetary factor. I don't know what went on between NASA and OMB. I haven't the foggiest idea what the discussions were this year, but they have been pretty tough over the past few years, and so with the push to get the shuttle back up and going and the cost that that is going to entail, I could very easily see that even if NASA was very desirous of returning to an ELV program, that the realities of Gramm-Rudman and everything else that now has descended upon us make that more difficult. That is just speculation on my part.

Mr. **Nagle**. Yes, I understand.

Somebody else want to take a shot at it?

Mr. **Parmet**. Charlie?

Mr. **Donlan**. I'm not sure I completely understand what your question is, sir.

Mr. **Nagle**. Well, I think that the conclusion of the panel, and I think implied from the questions of the chairman, there is probably a need that we consider ELV's. There seems, at least to me as a new member of the committee, to be a reluctance by NASA to consider or entertain that option. This question is really in two parts: First, is that correct? And, second, if it is, what can we do about it in terms of encouraging them to consider the ELV alternative?

Mr. **Donlan**. Well, there is no question over the years the theme has been to eliminate the ELV's and use the shuttle. Now with the advent of the *Challenger* accident, that philosophy has been modified and NASA finds itself in a position of being told, more or less, to use ELV's when they haven't in fact budgeted for them or planned to use them, so they are right in the middle of a metamorphosis of how to operate a mixed fleet. The recent discussions I have with NASA are, they fully expect to do that, but when and how and how it is to be funded is a matter of debate with the Congress, among other things.

Mr. **Nagle**. What can we do as an institution or as an oversight committee to encourage that move by NASA, other than provide ELV's—ELV's that I might add they don't ask for?

Mr. **Donlan**. Well, as I mentioned earlier, one of the problems has been, a lot of the payloads that were conceived several years ago—and it takes a big lead time—were planned to fly on the shuttle. They either fly on the shuttle or something like the *Ariane*. That may well be what happens. We'll see a drift toward the use of some of the foreign ELV's until such time as this country sees fit to fund and employ ELV's on its own.

Mr. **Nagle**. Well, let me give you an example of what I mean. We are going to be 50 launches behind, I think, by 1992, and that 50-launch schedule behind in terms of projects to go was assuming that we launched in January of 1989, which we are obviously now not going to do. I am one Member, at least, that thinks that probably that launch won't come until September, if then.

The 50-launch figure behind does not include launches for the Space Station, which I understand would mean someplace between

16 and 32 additional shuttle launches, and yet we have not heard from NASA any proposal that the ELV alternative be considered for any part of the station, even those parts that don't need them, that aren't man-required.

I think the word you used was "drift," is the right word, at least in my perception, and my question is not in any way antagonistic, but how do we perhaps charge with NASA rather than drift to the ELV category?

Mr. DONLAN. I don't know. I think we are just going to have to see. For instance, the Space Station itself, although we hear all these number of flights required, they can in fact be reduced. It is possible to put up a workable station with only eight flights as a minimum, and we may see modifications in a program like that to accommodate the payloads rather than using them all up on the Space Station. I have no further insight as to how they are going to solve that problem.

Mr. NAGLE. We don't really have a full understanding of what NASA tried to put in its budget this year because we are not privy to that, and we were just wondering whether it was NASA didn't put anything in or it was taken out as some level, like at OMB. We don't know the answer to that. Might that not be a start? If you find out what NASA's views are first, if they did put it in and it was knocked out, then you've got to go back to homeplate some way and say, "Hey, we need to take some action in this place rather than that place."

Mr. PARMET. I wish it were that simple. I wish we could just go ask them and they would say, but I don't have that perception.

Mr. NAGLE. Well, I am a simplistic individual.

Mr. PARMET. No, you're not, either, and I don't mean it that way, but what I mean is that they have certain obligations to the administration they represent. Those budget fights are always done generally, internally, not externally. Once the fight is over and we all walk out of the room, there is a reluctance of disclosure on all parts.

Mr. NAGLE. I see.

Mr. STEWART. There is one other sort of more fundamental dimension than we have been talking about. It is not clear to me, at least as an individual—this is not a panel responsibility particularly—but as to what this Nation as a nation is proposing to do in space. We know some very short-term kinds of things, but in terms of any sort of program that looks to the future in any kind of time frame on it, that doesn't seem to me to exist.

As a consequence, these decisions are all being looked at in a kind of ad hoc way. If there was a kind of consensus with the administration and the Congress and the American people as to what it was that we were going to be doing in all of these activities, it would help answer these kinds of questions. I know the Congress is central to those kinds of concerns, and I know this subcommittee has been very concerned about it for quite some time, but there has not been a definitive statement made in a long time, and that's part of the problem.

Mr. NAGLE. Let me take you up a step, then, and ask you about the proposal that we were briefed on yesterday, because certainly I think we would all agree that minimization of risk if we are going to use manned flights is absolutely essential. NASA is proposing the development of an advanced solid rocket motor or, as I am learning around here, an ASRM. One of their arguments for it is that this will improve the safety of the existing motor, the advanced solid rocket motor will, you know. Is this necessary, gentlemen? Do we need, in your judgment, an advanced solid rocket motor?

Mr. STONE. I will start off and then maybe Charlie could come in.

First of all, as you know, the payload has been degraded because of the fixes that have been put into the present shuttle. As far as safety is concerned, yes, safety can be increased, and reliability, but the other thing is to increase performance. To bring it up to the 65,000 pound payload originally designed to, in my estimation will take a new, advanced SRM. I think that it's something that we should look forward to, and as an individual of the panel—and I don't know how everybody feels about it—I think the panel would say that it should be pursued.

As far as increasing flight safety, the design that has taken place is a 1970 type of design, and obviously there have been improvements, so I think both safety and reliability can be improved. If we do increase the payload or performance, there are a few things you will have to be careful with. That is, the orbiter would probably need some type of modification and so would the external tank, so you are now looking at something besides the actual booster itself if you are going to increase its performance. If you don't increase its performance and stick with the 65,000 pounds of payload, there would be very little increase, although there will be some modifications to the orbiter and possibly the external tank.

Mr. NAGLE. Okay. Now are you comfortable, from your review, with the present—I mean, the cost is $456 million, I believe—I won't hold you to that figure—to develop the ASRM. Okay? I won't hold you to that figure because I don't want to even hold myself to it, but I think that's the range of it, from what I heard yesterday. Now is the extra lift that we are going to get, which I think is roughly 10,000 pounds——

Mr. STONE. Maybe 15,000.

Mr. NAGLE [continued]. Maybe 15,000, is that worth the cost in and of itself?

Mr. STONE. Do you want to answer that?

I think so personally. As a panel member I haven't given it that much study, but personally I think that in the 1990's or the early part of 1990, yes, it will be something that I think this Nation needs and I think we should go ahead with it.

Mr. NAGLE. Okay. Now weighing the improved performance, setting that aside, is it needed from a safety standpoint, from a reliability standpoint?

Mr. STONE. No. I would say from a safety point of view that the present shuttle with continuing modifications that normally take place in any type of a system, I think safety-wise should take care of itself.

Mr. NAGLE. So in your judgment, if I can just summarize that, Mr. Stone—I was getting a note here while I was listening——

Mr. DONLAN. If I might add——

Mr. NAGLE. If you could hold just for a second, Mr. Dolan—Mr. Donlan?

Mr. DONLAN. Yes.

Mr. NAGLE. I'm sorry.

Basically what you are saying is, safety is not a factor in the building of a new motor. The present motor can be made safe enough. Is that it? It is increased performance, in your mind, is what we are coming——

Mr. STONE. Well, the redesigned motor, yes, I think that as far as that is concerned, after all of the tests are completed and all of the certification plans, which include flight testing with proper instrumentation on it, after all that is accomplished, yes, I think that that would be safe enough.

Mr. DONLAN. This isn't particularly a view of the panel but in regard to safety of solid rocket motors, one of the problems has been, once you light that firecracker, you ride it until it burns out. I don't know how many know it, but the original shuttle decision was made to go with pressure-fed boosters.

Mr. NAGLE. Say that again?

Mr. DONLAN. The original decision was to use pressure-fed liquid boosters instead of solids, and the reason for that was that the pressure-fed booster or a liquid booster you can stop on the pad or anywhere in the ascent trajectory. The reason it was dropped at the time was, some of the estimates coming in were so high, from half a billion to a billion dollars more than the development of a large SRM, the decision was made to go with it because we had more experience with the large solids, and later on look at it.

That later on never came. In the past couple of years I have been involved with a study with an organization looking at this pressure-fed booster, and I was glad to see NASA is, in fact, including a study of the liquids in this recent announcement about the new studies.

Mr. NAGLE. Anybody else?

[No response.]

All right. Let me go back to Mr. Stone, if I could, just for a second. I am a little troubled. Would it be fair to say—let me ask it this way, and I am just trying to find out your consensus, I certainly don't mean to be adversarial—you are basically saying that the sole reason to build the ASRM is one of increased lift, that we can make the present motor safe enough. Is that true?

Mr. STONE. Yes, that's part of it.

Mr. NAGLE. Okay, and through that we get 15,000 pounds more lift, although I do think the figure is closer to 10,000 from what I have heard, but I will take 15,000. Is that that much of an advantage, to have 15,000 pounds more lift?

Mr. STONE. Well, originally everybody thought that a 65,000-pound payload was the payload that we should be lifting, and it has been degraded over a period of years. I think that we probably will find out that in the later years, that we are going to need that 65,000 pounds or maybe even 5,000 pounds more than that, so my answer would be yes.

Mr. NAGLE. Are there any projects on the board right now that call for this 65,000-pound lift between now and 1994?

Mr. **Stone**. There aren't any projects that I know of that require that heavy a load, unless you actually went back to Vandenberg, which would be a military-type load, and we haven't gotten that information.

Mr. **Nagle**. And on Vandenberg, I think we don't have any real use for it at this point from a shuttle launch capacity, that can't be done on an ELV.

Mr. **Stone**. Yes. Well, it seems to me that somewhere in the 1990's I am just anticipating that requirement.

Mr. **Nagle**. Now you know what the next question is. The next question is, if it costs $456 million to build an advanced rocket motor whose sole benefit is 15,000 pounds in additional lift, no projects which we have available to us until after 1994, unless we went back to Vandenberg for some reason and reopened the plant down there, what would be the effect of putting that money into ELV's or into heavy lift launch vehicle research or development of a heavy lift launch vehicle?

Mr. **Stone**. I think you have a very good point. In other words, developing the heavy booster could do the same thing. That is going to be a very costly project within itself, and I don't know if anybody has sat down and determined the economics of all of this. I think that we don't know what the military cargo will be as time goes on, especially in the 1990's, and I can just anticipate that it is a vehicle that would be worthwhile building, just from the past history of how vehicles grow and what is needed.

Mr. **Nagle**. The Air Force wants a heavy lift launch vehicle, I think, or at least they are intrigued by the idea of having one. Again, just looking for bang for the dollars, since we are in a period of time of scarce resources, would the panel as individuals or as members of the panel be more inclined to favor the development of a heavy lift launch vehicle as opposed to the ASRM?

Mr. **Stone**. I think there is one other point.

Mr. **Nagle**. Okay.

Mr. **Stone**. When I say safety and reliability, with that you need modifications of the present shuttle system. That is going to be costly. Now how many years in advance you can amortize this over in order to be able to determine what it means economically is something that you have to think about. Definitely there would be improvements that would have to be made to the space shuttle vehicle, the orbiter, the booster, and probably the external tank as time went on. Now if you say that "I am going to, in the early 1990's, kind of try to phase that out so that the other type of vehicles can take over," I think you just have a different type of a ball game.

Mr. **Nagle**. I'm not quite sure I understand your answer.

Mr. **Parmet**. Maybe I ought to put something in focus here. The basic purpose of our committee is safety, and the kind of questions you are asking are really those that belong to what I would call a corporate planning function: Where are we heading? What are our aims in life? To me they are not quite as clear as they should be because, number one, as John has indicated we don't have a finite, a clearly defined governmental plan, and secondly we don't have a coordinated military/NASA plan, and we think there is a lot of work that has to be done to get the people together to decide where the heck are we going. Once you decide where you're going, then you have a clearer picture of what you need to fill your requirements. I've got to say we can give you our individual views on that, but they are really not part of what our panel is here to say.

Mr. NAGLE. And I understand that, and I am just trying to more or less, if you will allow me, to pick your brains for a moment, because these are decisions we are going to have to make.

Mr. PARMET. Well, I think you need to get back into what I call corporate planning, and start having a finite and clearly-defined plan of a direction in which we want to head. Then the kind of answers that you are asking can be more easily answered, or at least attacked. I don't think—today you put so many caveats on every decision you make, you can go this way, that way or a third way, and you come up with a different answer economically and safetywise for different approaches.

Mr. STEWART. Norm, let me just throw in one other thought. Every now and then you kind of, if you sort of stand back and look at where you are, something jumps out at you. The thing that has jumped out at me recently, in looking at the whole re-flight process, NASA's preparation, getting the STS back up and running again, is its incredible complexity, and it is getting more complex all the time, not just the systems but the tests that we now are going to need to run, to make sure that the systems are working properly.

If any of you go back and think about what the original concept of the shuttle was, it was not that at all. It was to be a fairly routine way of easily getting into space, frequently, at low cost. For all sorts of reasons that I think have a lot to do with the fact that this is a radical concept, it's the first generation of a piece of equipment that can do the things the shuttle can do, it has turned out to be far more sensitive, far more difficult to operate than anybody ever thought it was going to be when it was originally conceived.

So it seems to me that one has to occasionally let common sense sort of enter into it and say, "Look, we have learned a lot from the shuttle." We are going to want to continue to fly it, but I personally would wonder why you would want to spend a great deal of money trying to upgrade a system which fundamentally isn't going to do, no matter what you do to it, what it is going to do that it was originally conceived of doing.

Now you could get a great, roaring argument going on that, but that is my personal view, and so I would say that we have to have a presence in space. This country is falling very far behind very rapidly, so that given the budgetary realities, I would think long and hard before I went much beyond those steps that permit us to fly a limited number of shuttle missions for the next 10 years or so, as safely as you reasonably can. I think you've got to do that, but beyond that I think you ought to be looking down the road a bit to another generation.

Mr. NAGLE. I agree.

Mr. Krone?

Mr. KRONE. Let me add one thing. Since we are really talking in terms of judgment and opinion now, as opposed to good, solid analytical economic analysis, you can do a good, solid economic analysis to determine whether or not it is more economically advisable to go with the ELV's or to go with improved shuttle payload, et cetera, but also coming into that are the unknowns relative to the kinds of payloads that you may have in the future, that couldn't go on the shuttle, et cetera. Therefore, I will express it as an opinion if nothing else, that it would be advisable for us, since the shuttle is a relatively old system in a technology sense, to go with a newer technology alternative, at the same time upgrading the current systems on the shuttle to make it as safe as possible and to operate at as high payloads as possible. So as an opinion, I would go with another system along with the shuttle.

Mr. NAGLE. Yes.

Mr. KRONE. And that would be, you would be looking at advanced manned systems, but for now I think from a technology standpoint it is, again opinion, more advisable to go with an unmanned alternative.

Mr. NAGLE. I was reading over the weekend—and I have the greatest subcommittee chairman in the world because he just lets me go, you know, and doesn't ring a bell on me—but I was reading over the weekend the history of space, and I'm sorry I can't even tell you the title of the book but it had to do a little bit with the period of 1954 to 1957 when we really had the technology to put a Sputnik into space, and not because of hard scientific analysis but because of Congress and the administration—it was basically bipartisan, partly Truman, partly Eisenhower—we kind of sat on the launch pad.

I am very, very concerned that we are sitting on a launch pad again today, not moving in any direction and simply upgrading the shuttle—and this is an opinion of my own, now—upgrading the shuttle motors, that in essence keeps us at the same level of competency, maybe safer but at the same level of competency and the same level of doability, and that we need to make some alternative decisions. Does anyone wish to disagree with that?

[No response.]

Okay. Now one other question for you, as long as I have you here, two last questions and I promise to be quiet.

Some observers have suggested that the cost of the solid rocket motors would be reduced, while their safety and reliability would be enhanced, if NASA would contract to have two competing suppliers of these motors rather than buying them only on a sole source basis. What do you think of that?

Mr. PARMET. Well, I will start out this one and anybody else can pitch in.

Mr. NAGLE. All those that work for Morton Thiokol are disqualified from answering, by the way.

[Laughter.]

Mr. PARMET. I can assure you that this is an independent opinion because I don't know very much about solid rocket boosters, but I would tell you this: that in any design where you want two sources for the same device, it is going to cost you a hell of a lot more money than it would with a single source. All you are really doing is having those two different companies building the same device compete with each other, and the only way they probably can is to improve the quality level a little bit. I don't think you will gain enough out of that to make a second source for the same device.

But if you say, "Okay, I want two competing guys to step in and each bring us the best possible solid rocket booster and bring us a finished design," I love that kind of competition. The business I was in for most of my life, that's the way we worked, and the guy who had the best product, that's where we spent our money. But in this case all the money comes from the front, and I don't see the gains from two sources to produce a single device, especially at the low rates of production that you get in this program. It wouldn't justify having a second source. That's my view. Does anybody else want to comment in that area?

Mr. STONE. Well, first of all I want to say I agree, and the reason for this is that I have been watching the growth taking place in both Morton Thiokol and NASA since they made their tests, and they are way up on the learning curve from where they used to be. This is very important.

Any other contractor taking this over as a second source would have to get up to this learning curve. Learning curve is not just building hardware, but it is how to work with the vendors, processing and all the specifications and many myriad of things. I have seen this growth and I applaud this growth and I think it's something that they are doing a good job on now, so as far as second source on exactly the same type of a vehicle is concerned, I would say no.

As far as competition is concerned, you are still talking about maybe five years from now because of the fact that it is a different design entirely and it has to be proven, and usually these type of systems take that long.

Mr. NAGLE. Mr. Himmel, do you agree?

Mr. HIMMEL. Yes. I think that——

Mr. NAGLE. Mr. Donlan, do you want to cast a vote here?

Mr. DONLAN. I agree with that, but I think I would like to say something about the technology of the shuttle. There seems to be an impression that it is 1970 technology. The only obsolescent technology in the shuttle is the SRM's. The shuttle itself will have new electronics, new computers. It is still the best thermal protection system we know how to make, and if that system is upgraded it's hard to see how any new system can be any better than that at this time, because it does represent—except for the SRM, which is an older technology—a very advanced system.

Mr. NAGLE. On your technology question, are we locking, if we go with this ASRM, are we locking ourselves into present technology for the mid-1990's, at a time when there might be other technological breakthroughs in terms of rocket motors?

Mr. DONLAN. Well, if this—what is it called, ASAM?—that presumably is intended to tap any new technology in the solids, but simply to go with a replacement of the present ones would be using old technology.

Mr. NAGLE. The last—Mr. Himmel?

Mr. HIMMEL. Just one point, that any time you make a design decision, you are locked into a technology, so that if you decide this year to go to an ASRM and decide what it is going to be and how it is going to be made, then you are locked into the technology as it exists then, unless something occurs downstream which says, "My

God, it's so good I can taste it." That rarely occurs because it is very expensive to change your mind in midstream.

Mr. **Nagle**. The question itself may have been asked previously, and if it has I withdraw it, but in looking at the report and your recommendations and viewing those, I am kind of puzzled almost by the question—not that your report isn't good, not that you haven't done a fine job, I mean that sincerely and I offer you my thanks—but I am kind of puzzled by the fact that many of your recommendations seem to me to be things that should have been in place, things that frankly, if we were planning and moving through an agency that was 30 years old, should have been anticipated from past incidents. I am kind of curious to know if you can tell us, why did the system reach to the point it did, where some of your recommendations which are most obvious are necessary to make as recommendations?

Mr. **Parmet**. One thing I can say is, just because they are obvious doesn't mean they are going to get done. Part of what I saw, coming from the outside world and looking at NASA, is they are in a sense very tradition-bound. They have done things a certain way for many, many years, and just because the new guy on the block comes in and says, "I think there are some better ways to do something," doesn't mean that they are better, number one, or number two, that even if they are better, that they are going to listen to you, because they are comfortable with what they're doing.

That is part of the problem why things don't change, and part of the reason why things don't change is because people inside feel they are satisfactory. Certain designs are okay, whereas someone who comes in with a new view says, "Gee, that really isn't very good." You insult them. Those are some of the problems I see in coming in to try to convince people to do things differently or better.

I have been told, for instance, on some of my ideas on management, "They will never work in NASA," and that is because of the very nature of the organization. Some of it I have learned is probably correct, because you've got a diverse organization that is spread out all across this country, and to try to apply, let's say, a central pyramid to that organization just won't work very well without throwing out the whole organization and starting over, and you can't do that.

Well, those are some thoughts that come immediately to mind to respond to what you said.

Mr. **Nagle**. Does anybody else want to answer?

Mr. **Stewart**. Yes, I will sound off, as my colleagues know I would.

Mr. **Nagle**. Are you Mr. Stewart? Are you the one that——

Mr. **Stewart**. I am Mr. Stewart, yes.

Mr. **Nagle**. You are Mr. who?

Mr. **Stewart**. Stewart.

Mr. **Nagle**. You are Mr. Stewart. Are you the one that hit Mr. Parmet? [Laughter.]

Mr. **Parmet**. Well, we came close.

Mr. **Stewart**. We touched on it in various parts of our report, and I think it gets to some of the areas where I think now there has been encouraging progress. One of the great puzzles in government or in private life, is what makes some organizations successful and others not? It's obviously a lot of things. It's clear that the organizational lines in NASA got all twisted around. Headquarters wasn't really leading the organization. The centers were really leading the organization, and in a very competitive way oft times. The battle over turf which we talk about, all of that was, I think, quite real.

When that happens, responsibility and authority is not clear, accountability is not clear, discipline suffers. You get into a kind of downward spiral, and I think that is really what NASA gradually slipped into over time. It was not something that all of a sudden wasn't there. It was aided and also abetted by the pressure that NASA was under to meet a schedule that was essentially unmeetable, given the technology they had to work with.

When it was declared by the White House and by NASA at the end of the fourth flight that the shuttle was now operational, that created a whole set of expectations which NASA then did their best to meet. They went out and they sold space on the shuttle like they were selling soap. They had promotional campaigns, and they did all kinds of things, and they built themselves into, in a sense, an unwinnable situation. By selling space, they then had an obligation to deliver it to the customer. That meant an unrealistic flight schedule, and all of those things contributed to the breakdown of the organizational excellence that had been NASA's hallmark.

All of this suddenly became clear when the *Challenger* blew up, so now it is clear and people are going about to fix it. I think they are proceeding in a generally satisfactory way and an encouraging way, but it is a very complicated question. Why an organization gets off in that kind of a circumstance when there were still excellent people throughout NASA and are still excellent people, and people who really cared, is a puzzling, difficult question. A lot to do with personal attitudes, work environment, sort of a political environment in which NASA operates—all those things were contributing factors, it seems to me.

Mr. NAGLE. So what we're saying here is, you need a periodic outside critical review of an organization such as this in order to make sure that internal policies don't become—internally they don't become complacent.

Mr. STEWART. That's right, and I think if we have anything as a panel to say to that issue, if you look back at our report several years prior to the *Challenger* accident, we were sort of touchy on some of these things but we didn't do it as forcefully as we should have. I think that is something we have learned. We didn't speak as loudly and as clearly as we should have.

Mr. NAGLE. That was going to be my next question: What happened to the Aerospace Safety Advisory Panel?

Mr. STEWART. Well, we weren't—we touched an awful lot of those issues. We talked about flight rates. We talked about management breakdowns and so forth, but we did not do it with the kind of clarity and force that, in retrospect, we should have.

Mr. NAGLE. Well, it is partially a need, I think—and then I am done, with this statement—it is partially a need for all of us, even if we support the space effort, to understand that support and criticism aren't incompatible.

Mr. STEWART. Right.

Mr. NAGLE. Thank you very much, gentlemen, for your patience and indulgence.

Mr. NELSON. Thank you, Mr. Nagle, for some excellent questions. Let me just add a chairman's editorial here. I think what the gentlemen are saying with regard to the SRB question that you asked, and I happen to agree with them, is that you want to make sure that the existing SRB's are fixed. They have a responsibility as a panel to see that that's going on, and they have said that they think that they are being fixed. Of course, that is something that will continue to monitor, and we will go to whatever test firings that we need to go to as a committee and so forth.

I think they are additionally saying that if this is going to be your manned system that you are going to fly well into the next century, until we develop another manned vehicle, of which we are researching that right now, that you want to provide the propulsion system that could be up-to-date, state-of-the-art, and therefore the advanced solid rocket motors that would carry you from a period of 1995 when they would be operational on into the year, however long the shuttle is flying—2005, 2010, whatever the date is.

So as you are looking into the question of the advanced SRM, I think I come down on the side of this of just more instinct and that is, if I am going to be riding that shuttle all the way to the year 2010, do I want a more advanced solid rocket motor that is propelling me, when I can get it in place? I think the answer to that, my instinct tells me, is yes.

So I think—would you all say that what I have summarized, these comments, is a fair characterization of some of your deliberations?

Mr. KRONE. I will make a comment on that. I just wouldn't limit it to the advanced solid rocket. I would look at, under that scenario, advanced systems that would give us a greater capability from the economic standpoint.

Mr. NELSON. A great capability what?

Mr. KRONE. From the economic standpoint, in other words, more payload. Incidentally, the payload question is one relative to the number of flights you have to put up to put the amount of payload in tons into space, not necessarily only the fact that do you need to put up a 65,000-pound payload, you know. If you are going to develop an advanced booster, you want to look it from the standpoint of going to the year 2005 or 2010, and building the one that is going to do the best from that standpoint, not necessarily just an upgrade of our present, you know, the one that we are going to fix to make it work until 1995 or so.

Mr. NELSON. Now one of the things that you as a panel and we as a committee have to worry about on safety is, do you get into some safety problems when you put increased performance and a new kind of propellant and a thinner skin on those SRB's, and does that give you some new kinds of safety things that we can't judge at this point?

Mr. KRONE. That's equivalent to the question of the new systems themselves, for example, the Aerospace Plane, which is touted by some as being an eventual replacement for the shuttle. There are technologies that can improve the shuttle capabilities above solid booster rockets. You know, solid booster rockets are, technologywise they are fairly static. You know, we don't have much opportunity to really get a substantial increase in performance out of the shuttle as long as we stick with solid booster rockets. Specific impulse (SP) comes into it, and what's the limit, as well as the safety factors in regard to the thickness of the shell and the materials we could use in the shell and all that. I mean, there are other, more advanced propulsion systems coming along that could be used as a booster.

Mr. NELSON. Okay. Let me see if I can wrap up here. Do you want to suggest to us anything that we can do to assure that there is not undue pressure to increase the flight rates in the future?

Mr. PARMET. I think NASA can retain optimistic objectives as long as they recognize what reality is. Some of us will probably continue to state publicly our views of what realistic rates are, even though NASA may say, "We want to plan for 16. We want to do the logistics for 16, and if we don't make 16, we will still have everything in place that will later get us there.

I think there is plenty of pressure on them right now to do the job right, and with our comment which we have expressed several times here, "safety first and schedule second." I think that has got to be, within some realm of reason, the guidemark for this return to service.

Mr. STEWART. What you can do, Mr. Chairman, I think as a committee is to continue to look at the issue of how the shuttle is serviced for reflight and the kind of procedures that are in place, the kind of discipline that is displayed in following those procedures, because that is where the ultimate safety factors get handled. As long as there is a pretty good consensus that we know what we're doing and we've got procedures set out, we're not working excessive overtime rates—the kind of evidence that was clearly there for all of us to see—those are the sorts of things that I think require occasional oversight by the committee, to see that that key element of preparing the shuttle for flight, the whole turn-around process, is being handled properly. As long as that is being done, I think the flight rate will take care of itself because it is going to take a while to get those shuttles ready to fly again if you do it right.

Mr. NELSON. Comment, if you will, on just a couple more of your conclusions here: that with regard to the space shuttle, there should be more testing and verification of loads on the orbiters.

Mr. PARMET. Mel?

Mr. STONE. The orbiter itself has had a few problems in the past because the loads have increased on the wings themselves, due to interference of the fuselage and the plume effect. Although the orbiter itself is instrumented, there was never a real calibration test on the wing of the orbiter itself. We have requested that NASA look into this, and they agree with us but there hasn't been any budget set forth, so we don't see anything going forward.

We believe that it is a necessary thing and should be done during this down time, because we don't think that at the present time that the loads are known that well. It takes a calibration with strain gauges and not with pressure gauges, as was used in the past, because they have their own problems. There were about 250 pressure gauges used to determine loads, and these transducers have their own problems of tripping and actually nullifying the pressure over it in certain areas. So we have said we think that at this time we should have a completely calibrated orbiter, and it should be done before first flight so that when it does go up, you know what the loads are.

Mr. NELSON. Okay, and we will follow through on that. Thank you for sharing that with us.

Here is another one of your statements: "Changes being made in the main engine do not add any significant improvement to its margin to failure." You say further that the current engine should be operated at power levels no higher than 100 percent of rated thrust.

Mr. HIMMEL. I think that our actual statement is that 104 percent, but that we believe it would be prudent to operate at 100 percent until you get some flight time. Any certification program has a finite duration, a number of hours—or seconds, in the case of a rocket engine—of operation, and if you can fly at less that 104, by all means do. That gives you more margin, lower temperatures, lower speeds on the turbine machinery, things of that nature, which give you—I hate to say "more safe" but a situation which is better and less stressful on the engine.

So in essence we're saying unless you have to go up to that level, don't do it, if it's possible to do it. Some of the trajectories and some of the payloads won't require it. In the meantime, get your data as you fly, continue your ground test program, and then you can get the statistically significant background of data to be able to tell you where you are.

Mr. NELSON. Okay. One of your other conclusions was, "Improved methods for demonstrating failure mode margins are required for the main engine."

Mr. HIMMEL. I think that we were alluding there to the fact that it was frequently quoted, the engine's margin was quoted in terms of lifetime, and that is not an appropriate designator. It's perfectly all right if you want to talk about what the mean time between failures might be, because you are dealing with phenomena which have to do with life, but that doesn't mean that if you exceed that set point by a small amount, you might fracture or break the part.

Because it is very difficult, very expensive to destroy an engine, which is what happens when you incite a failure, the engine components have not necessarily been brought up uniformly to ascertain exactly what the stress margins are, for example. You have to go through that entire process, and it's expensive.

What we're suggesting is that there are newer methodologies and perhaps subsystem-level testing, which would be less expensive than testing on a complete engine, through which to determine what your actual margins are, because right now, for example the engines that are currently in the certification program are being run primarily at 109 and 104, with a few moments or seconds at 11 percent, but how long can it last at 111 percent and how close are you to the edge? What happens if you go to 112? That's the kind of question you have to answer, and that's what we're suggesting.

Mr. NELSON. Mrs. Morella?

Mrs. **Morella**. I'm sorry that I didn't hear the panel, but I want you to know in talking to one of our key staff people—and we have some very prominent people who work on the staff—she told me she was exceedingly impressed by what the panel said, to the point, Mr. Chairman, that she is going to be kind enough to do a summary for me of the transcript. Even from listening to the chairman and your responses, I want to thank you also for the candor.

I was curious about, you said that we should monitor prior to the shuttle flight. I didn't know what kind of timetable you have in mind. How often do you monitor? What is our responsibility in terms of looking into that and asking for updates and whatever? Whoever wants to answer.

Mr. **Stone**. Well, I think you are doing it now very effectively, and I don't think it's really a question—the first reflight is not really the question. I think the thing that everybody will be worried about or will worry about is, where are we when we are in the 10th flight now, after STS-26, when things kind of tend to settle back down into a routine? The chairman said, "How do we avoid the process of exceeding a flight rate that is prudent, a flight schedule that is prudent?"

I think as part of your annual oversight hearings, I think that would be kind of a thing that you ought to inquire about. That would be an appropriate thing to do as part of the annual oversight process, as to the nature of the turnaround time, the kind of procedures and discipline that is being followed. I think that the shuttle processing contractor has got something to say on that. I think that all this panel probably would. We are going to continue to follow it, and perhaps some of the National Research Council groups are going to look at it also, but I would think an annual kind of look at it, once we get through this initial return to flight, would be very important.

Mrs. **Morella**. Do you think that's enough, adequate?

Mr. **Stone**. Yes, I think probably so. I think that because this panel will continue to look at it, and I think we have learned that if we see something that really alarms us, we will be ready to pass that on the administrator and to the Congress if necessary. But I think NASA is responsive at this point. You shouldn't take that to suggest that NASA isn't responding to these ideas and suggestions now.

Mrs. **Morella**. No, I believe they are, and I would certainly encourage you to make sure that you alert this committee, too, at certain times, so that we can continue to monitor or do what is our responsibility. Thanks very much.

Thank you, Mr. Chairman.

Mr. **Stone**. There is a specific area of monitoring technically that we have suggested and we believe NASA is going along with. That is that we think that the first year's flight should be heavily instrumented to be monitored, so that information on structure, safety, reliability, performance and all these things can be gathered. It should be a part of the certification program, so that they don't depend upon the tests that we have as ground tests, but part of the certification under a well-monitored, heavily-instrumented system would take place. We have suggested this. The NRC committee has suggested this, and I believe that is one of the things that NASA is going to do.

Mrs. **Morella**. Splendid. Thank you very much.

Thank you, Mr. Chairman.

Mr. **Nelson**. As we close our hearing, I think it is worthy of note that Mr. George Rodney has sat through this entire hearing. That is a welcome change in NASA's attitude, and I appreciate your attitude, Mr. Rodney, and the vim and vigor with which you are approaching this safety job of yours in NASA.

Mr. **Rodney**. Thank you.

Mr. **Nelson**. The meeting is adjourned. Thank you all very much.

[Whereupon, at 4:22 p.m., the subcommittee adjourned subject to the call of the Chair.]

SPACE SHUTTLE RECOVERY: VOLUME 1

THURSDAY, APRIL 30, 1987

House of Representatives,
Committee on Science, Space, and Technology,
Subcommittee on Space Science and Applications,
Washington, DC.

The subcommittee met, pursuant to notice, at 9:55 a.m., Hon. Bill Nelson (chairman of the subcommittee) presiding.

Mr. Nelson. Good morning.

Today we are going to be continuing our current series on the oversight hearings on the shuttle recovery effort. Our intent is to gain new insights from other independent review panels and committees, so that we will be better prepared to establish the necessary Congressional policies and priorities to help guide the return of the shuttle to safe flight status, as well as placing the entire civilian space program back on a healthy footing.

At today's proceedings we will be hearing from witnesses from the National Research Council and the NASA Advisory Council. The first witness will be Dr. Stever, who is the Chairman of the Committee of the National Research Council that is overseeing the redesign of the SRB. And then we will hear from Dr. David, who is serving as Chairman of the Panel of the National Research Council that has produced independent estimates of the likely launch rates. Finally, we will hear from Maj. Gen. Jasper Welch, who has been chairing the Task Force under the NASA Advisory Council which has conducted a mixed fleet study.

So I would like to thank you all for being with us and ask our ranking member, Mr. Walker, for his comments.

Mr. Walker. Thank you, Mr. Chairman. I have no opening statement.

Mr. Nelson. Okay. Dr. Stever.

STATEMENT OF DR. H. GUYFORD STEVER, CHAIRMAN, PANEL FOR THE TECHNICAL EVALUATION OF THE REDESIGN OF THE SPACE SHUTTLE SOLID ROCKET BOOSTER, NATIONAL RESEARCH COUNCIL, WASHINGTON, DC, ACCOMPANIED BY DR. MYRON F. UMAN, PANEL PROJECT DIRECTOR

Mr. Stever. Mr. Chairman, members, I am pleased to appear before you today in the capacity as chairman of the NRC's Panel on Technical Evaluation of the Redesign of the Space Shuttle Rocket Motor.

I am accompanied by the Panel's Project Director, Dr. Myron Uman.

Mr. Chairman, I have shortened the text which I handed in, and I would like to read this short version, but we would like the total text entered in the record.

Our panel was organized at the request of NASA in response to a recommendation of the Rogers Commission. Members of the panel are listed in the attachment. Our task, which is also attached, is to provide the Administrator of NASA with an independent technical evaluation of the redesign activity. While we are often called an oversight panel, we actually do not exercise program responsibilities or make recommendations regarding operational decisions. We carry out our task by developing findings, conclusions and recommendations regarding technical aspects of the new designs, as well as the program to test, verify and certify them.

Those results are presented in the form of a letter report to the Administrator. We have issued three reports to date. Each of our reports is made available to the public without restriction and immediately after we complete them.

The panel obtains the necessary details of the new design and test program from the frequent technical discussions with members of the redesign team, comprising engineers and others from NASA and its contractors and other knowledgeable people in the appropriate technical communities.

In this regard, I am pleased to acknowledge complete cooperation of everyone in NASA, Morton-Thiokol, and other organizations whom we have asked for help.

My testimony today is organized as a series of comments of the current status of the program, in light of the recommendations made by the Rogers Commission and your committee's investigative report.

The observations are based on findings, conclusions and recommendations contained in our reports.

First, in response to the Rogers Commission—to the recommendations of the Rogers Commission, the redesign team has focused intensely on those designs that it judged to be feasible for meeting the objective of improved safety, while returning the shuttle to flight as soon as possible.

Emphasis, consequently, has been placed on the maximum use of existing hardware and modifications based on forgings ordered in July 1985. Some valid design options, though considered, have not been given serious development effort. Several have been reintroduced into the program recently as long-term alternatives in response to strong recommendations of our panel and others.

The testing program has been organized primarily to verify the adequacy of the chosen baseline design, rather than to discriminate among design options. Because the program lacks concurrently developed alternatives for major components of the design, the redesign effort would be substantially extended if tests showed that any component of the baseline design is inadequate, with a loss of valuable time before safe and reliable shuttle flights can resume.

Work performed to date by the Accident Investigation and Redesign Teams has greatly improved our understanding of how solid rocket motor joints work. Tests of the new joint designs will have to be performed, however, before we can state with confidence that they are fully understood and verified.

On the question of the integrity of the structure and seals, specifications and design requirements have been issued that, if met, will assure the integrity of the joints under the most severe operating conditions anticipated, and in the presence of inflicted damage.

Thus far, our review indicates that there is a good probability that the criteria will be met.

Design criteria for the motor in the verification program have also been established to assure that the integrity of the joints is insensitive to dimensional tolerances, assembly procedures, environmental effects, effects of recovery and reuse, and other factors.

The extent to which the new designs will meet all of these objectives can only be determined, however, in the test program and through experience, flight experience.

The Rogers Commission also recommended the design certification include tests which duplicate the actual launch configuration as closely as possible over the full range of operating conditions. The program includes full duration ground firing of motors that would duplicate the designs that are intended to fly as closely as possible. Firings are planned at low and high temperatures. The use of heaters to condition the O-ring seals to a nominal operating temperature mitigates concerns about effects of low temperature on seal performance.

On the question of horizontal versus vertical testing, neither horizontal nor vertical static firings can faithfully simulate the exact conditions of flight. However, provided that full duration ground tests incorporate simulation of the important dynamic loads experienced at launch and during flight, horizontal testing should be appropriate.

Turning now to recommendations of House Report 99-1016, on the question of new and more accurate performance specifications, NASA has written new performance specifications that clarify the intended range of operating conditions including temperature, and the redesign team is implementing them.

The new design of the case field joint incorporates heaters to assure that the O-rings' seals are at a safe operating temperature when the ambient temperature is low. The redesign team is also addressing all previously identified design weaknesses and in-flight anomalous behavior and failures which might affect flight safety.

Since the various accident investigations were completed, additional studies and tests have identified specific weaknesses in the design of the original case field joint. Some of these deficiencies, all of which are being corrected in the redesign program, may also have contributed to the accident.

Other weaknesses have been identified and are being addressed to the extent that they affect safety. Prominent examples are the aft attach ring, the aft skirt, and the case-to-nozzle joint. While the verification program is intended to assure that the design works as intended and is safe, not all conditions of flight can be tested on the ground. The redesign effort must include a program to gather and evaluate performance data and, as necessary, make improvements to the design.

We have recommended that NASA establish and maintain a strong directed program for continued evaluation and improvement in reliability after flights are resumed. In the longer term, completely new designs, possibly radically different from the current one, may be preferred to enhance safety or improve reliability, performance or cost-effectiveness.

NASA should also pursue a program to develop the next and future generations of motors for use in the space transportation system.

On the question of the use of x-ray and other techniques to inspect the motors before flight, the redesign team has done an extensive assessment of the available techniques for nondestructive evaluation of the manufacture and assembly of solid rocket motors closely supported by similar activities conducted by the Air Force Space Command.

Based on these assessments, the team has adopted a plan for nondestructive evaluation that attempts to provide for the optimum application of these techniques to the redesigned shuttle booster.

On the manufacture of critical items, the panel has urged the redesign team to develop improved controls on supplied parts and materials, and noted that those used in the testing program should be subject to quality control similar to those imposed on the qualification motors and flight boosters.

It is my impression that understanding of critical processes and materials is significantly improved.

On the question of case growth, NASA believes that it understands the case growth phenomena and can take account of it empirically in the design, as well as in processing segments.

Effects on the reuse of new case segments that incorporate the capture feature remain to be determined. Regarding the introduction of all the anticipated thermal and structural loads into the test program, as I indicated earlier in my testimony, the panel regards the introduction of realistic dynamic loads on the booster to be critically important for verifying the design.

We must remember, however, that no ground test can ever exactly duplicate all the loads that are experienced—that are expected to be experienced in actual operations since the restraints on the boosters during ground tests will differ from those during flight.

The panel is continuing to review the design of the new dynamic test stand and other related thermal and structural tests to determine if NASA is doing the best possible job.

Mr. Chairman, that concludes my abbreviated form of the testimony, and I—except to state for the record that our panel is impressed with the dedication and hard work of the design team—redesign team, and I think they deserve the praise from the nation for diligent efforts under stressful conditions.

[The prepared statement of Mr. Stever follows:]

Testimony of

DR. H. GUYFORD STEVER, Chairman
Panel on Technical Evaluation of the Redesign
of the Space Shuttle Solid Rocket Booster
NATIONAL RESEARCH COUNCIL

before the

Subcommittee on Space Science and Applications
U. S. HOUSE OF REPRESENTATIVES

April 30, 1987

Mr. Chairman, I am pleased to appear before you today in my capacity as chairman of the NRC's Panel on Technical Evaluation of the Redesign of the Space Shuttle Solid Rocket Booster. I am accompanied by the Panel's Project Director, Dr. Myron F. Uman.

Our Panel was organized at the request of NASA in response to a recommendation of the Rogers Commission. (Members of the Panel are listed in Attachment A.) Our task (Attachment B) is to provide the Administrator of NASA with an independent technical evaluation of the redesign activity. While we are often called an oversight panel, we actually do not exercise program responsibilities or make recommendations regarding operational decisions.

We carry out our task by developing findings, conclusions, and recommendations regarding technical aspects of the new designs as well as the program to test, verify, and certify them. The results are presented in the form of letter reports to the Administrator. Thus far, we have issued three reports (Attachments C, D, and E, respectively). Each of our reports is made available to the public without restriction.

The Panel obtains the necessary details of the new designs and test program from frequent technical discussions with members of the redesign team, comprising engineers and others from NASA and its contractors, and other knowledgeable people in the appropriate technical communities. I am pleased to acknowledge in this regard the complete cooperation of everyone in NASA, Morton-Thiokol, Inc., and other organizations whom we have asked for help.

My testimony today is organized as a series of observations of the current status of the program in light of recommendations made by the Rogers Commission and your Committee's investigative report (House Report 99-1016). The observations are based on findings, conclusions, and recommendations contained in our reports.

RECOMMENDATIONS OF THE ROGERS COMMISSION

No design options should be prematurely precluded because of schedule, cost, or reliance on existing hardware. (p. 198)

The redesign team has focussed intensely on those designs that it judged to be feasible for meeting the objective of improved safety while returning the shuttle to flight as soon as possible. Emphasis consequently has been placed on the maximum use of existing hardware and modifications based on forgings ordered in July, 1985. The design has also been constrained by a reluctance to venture too far from prior experience. Consequently, some valid design options, though considered, have not been given serious development effort. Several have been reintroduced into the program recently as long-term alternatives in response to strong recommendations of our Panel and others. The current redesign program envisions making only those changes it regards as mandatory to improve safety. Changes that some program design engineers would like to see incorporated which might improve the design in other ways will not be accomplished in the program as currently envisioned.

The testing program has been organized primarily to verify the adequacy of the chosen baseline design rather than to discriminate among design options. As a result, alternative designs will not be introduced into the test program unless tests demonstrate that the baseline design does not meet the requirements or specifications of the program. Because the program lacks concurrently developed alternatives for major components of the design, the redesign effort would be substantially extended again if tests showed that any component of the baseline design is inadequate, with a loss of valuable time before ~~safe~~ and reliable shuttle flights can resume.

The joints should be fully understood, tested, and verified. (p. 198)

Work performed to date by the accident investigation and redesign teams has greatly improved understanding of how solid rocket motor joints work. The new case field joint design selected by NASA appears to have eliminated the basic weaknesses of the earlier design that contributed to the accident. Tests of the new joint designs will have to be performed, however, before we can state with confidence that they are fully understood and verified. The Panel has recommended that the redesign team institute a practice of forecasting test results and establishing success criteria *a priori* to enhance confidence in its understanding. We are pleased to note that this practice is now being introduced into the program.

The integrity of the structure and of the seals of all joints should be not less than that of the case walls throughout the design envelope. (p. 198)

Specifications and design requirements have been issued that, if met, will assure the integrity of the joints under the most severe operating conditions anticipated and in the presence of inflicted damage. Thus far our review indicates that there is a good probability that the criteria will be met. However, the extent to which the integrity of the structure and joint seals approaches that of the case walls can only be verified in the test program. Full scale tests of the new designs have not begun yet, so it is premature to reach a final judgment on this question.

The integrity of the joints should be insensitive to: dimensional tolerances, transportation and handling, assembly procedures, inspection and test procedures, environmental effects, internal case operating pressure, recovery and reuse effects, and flight and water impact loads. (p. 198)

The design criteria for the motors and the verification program have been established with this intention. The extent to which the new designs will meet all of these objectives can only be determined, however, in the test program and through experience. The redesign team has these aspects under consideration. The Panel has expressed concerns about the potential for reusing the case joint and about the stringent dimensional tolerances and assembly procedures for both the case field joint and case-to-nozzle joint. It appears as if the assembly procedures will have to be tightly controlled. An on-going program to evaluate test and operational data after flights resume is important both for assuring confidence in the new designs and for guiding future improvements.

The certification of the new design should include: tests which duplicate the actual launch configuration as closely as possible and tests over the full range of operating conditions, including temperature. (p. 198)

The certification program includes full-duration ground firings of motors that should duplicate the designs that are intended to fly as closely as possible. Many tests are conducted under nominal conditions, but full-duration ground firings of flight designs are planned for the extremes of temperature. The use of heaters to condition the O-ring seals to a nominal operating temperature mitigates concerns about effects of low temperature on seal performance, but at the expense of both added weight (hence reduced performance) and changes in the launch sequence.

Full consideration should be given to conducting static firings of the exact flight configuration in a vertical attitude.

We believe that the question of vertical vs. horizontal testing has been carefully considered. Neither horizontal nor vertical static firings can faithfully simulate the exact conditions of flight. However, provided that full-duration ground tests incorporate simulation of the important dynamic loads experienced at launch and during flight, horizontal testing should be appropriate. Introduction of dynamic loads is more important than the attitude of the test article and the small added benefits of vertical testing do not appear to warrant the additional time and resources required to build a vertical test stand. We are pleased to note that the redesign team is well along in implementing our recommendation to build a new horizontal test stand that will allow for the simulation of dynamic loads in full-scale, full-duration firings.

RECOMMENDATIONS OF HOUSE REPORT 99-1016

NASA should write and issue a new and more accurate performance specification ... for the Solid Rocket Motors, with an adequate margin of safety for unusually low temperatures. (p. 10)

New performance specifications that clarify the intended range of operating conditions, including temperature, have been written and are being implemented by the redesign team. The new design of the case field joint incorporates heaters to assure that the O-ring seals are at a safe operating temperature when the ambient temperature is low.

The Panel has expressed concern that the separation of responsibilities for defining requirements and designing the booster is not sufficient and that waivers from the requirements can be approved by persons with managerial responsibility for the design. Proposing waivers or revising specifications to match a particular design should be subject to the most careful scrutiny.

The Committee ... believes it is more appropriate to be more explicit in identifying the weaknesses in the (original) joint design that need correction. (p. 10)

NASA should ensure that before reinstituting Space Shuttle operations, it fully understands and has corrected all instances of serious in-flight anomalous behavior or failures involving mission critical pieces of flight hardware. (p. 15)

The redesign team is addressing all previously identified design weaknesses and in-flight anomalous behavior and failures which might affect flight safety. Since the various accident investigations were completed, additional studies and tests have identified specific weaknesses in the design of the original case field joint. Some of these deficiencies, all of which are being corrected in the redesign program, may also have contributed to the accident. In addition to those in the field joint, other weaknesses have been identified and are being addressed to the extent that they affect safety. Prominent examples are the aft attach ring, the aft skirt, and the case-to-nozzle joint.

While the verification program is intended to assure that the design works as intended and is safe, not all conditions of flight can be tested on the ground. Thus, verification of some aspects of the design can only occur as flight experience is gained. The redesign effort does not end with the next flight but must include a program to gather and evaluate performance data and, as necessary, make improvements to the designs.

In its most recent report, the Panel concluded that before the accident the ongoing technological program, aimed at resolution of anomalous behavior of the SRM, was limited. We have recommended that NASA establish and maintain a strong directed program for continued evaluation and improvement in reliability after flights are resumed.

In the longer term, completely new designs, possibly radically different from the current one, may be preferred, for example to enhance safety or improve reliability, performance, or cost effectiveness. The nation's manned space flight program cannot afford to continue to rely on older technology indefinitely into the future. Consequently, we have stated our belief that NASA should also vigorously pursue a program to develop the next and future generations of motors for use in the space transportation system.

NASA should consider reinstating full X-ray inspection of the propellant and insulation for all motors used on succeeding flights until new, more accurate inspection methods can be developed and implemented ... . (p. 18)

NASA ... should investigate the development of new, more accurate inspection techniques which can detect ... potential defects that cannot be detected by X-ray inspection. (p. 18)

The redesign team has done an extensive evaluation of the available techniques for non-destructive evaluation of the manufacture and assembly of solid rocket motors. This evaluation has been closely supported by similar activities conducted by the Air Force Space Command. Based on the evaluation, the team has adopted a plan for non-destructive evaluation that attempts to provide for the optimum application of these techniques to the redesign shuttle booster. I am encouraged by the close technical relationships that have been established between NASA and the Air Force to assure that both institutions are fully aware of the other's work in the development and implementation of nondestructive testing techniques. The Panel will continue to follow developments in this area.

NASA should require the manufacture of critical items, such as the O-rings, to be designated as critical processes. (p. 18)

The Panel has urged the redesign team to develop improved controls on supplied parts and materials and noted that those used in the testing program have to be subject to quality controls similar to those imposed on the qualification motors and flight boosters. In addition, we have taken the initiative to organize several technical interchange meetings among representatives of the redesign team, subcontractors that supply critical materials or perform critical processes, and the Panel; it is my impression that these meetings have helped significantly in NASA's improved understanding of critical processes and materials.

NASA ... should resolve ... the cause of SRM case size growth and its impact upon booster and Shuttle performance, reliability of refurbished SRM case segments, and safety. (p. 19)

NASA believes that it understands the "case growth" phenomenon and can take account of it empirically in the design as well as in processing segments. Effects on the reuse of new case segments that incorporate the capture feature--including specifications for and refurbishment of finishes of the sealing surfaces, metal fatigue, and other factors--remain to be determined. The ability of case segments and other reusable parts to meet the goal of 20 reuses cannot practically be tested before the resumption of flight; only time will tell, demonstrating another reason for a continuing program of test and evaluation after flights resume and well into the future.

In establishing a test program to certify the new Solid Rocket Motor design, NASA should consider the feasibility of including in combination and in the proper sequence all of the thermal and structural loads expected to be experienced ... during ignition, lift-off, and flight. (p. 20)

As I indicated earlier in my testimony, the Panel regards the introduction of realistic dynamic loads on the booster to be critically important for verifying the design. We must remember, however, that no ground test can ever exactly duplicate all the loads that are expected to be experienced in actual operations since the restraints on the booster during ground test will differ from those during flight. The Panel is continuing to review the design of the new dynamic test stand and other related thermal and structural tests to determine if NASA is doing the best possible job.

The program includes at least one full-scale, full-duration ground firing with dynamic loads before the next flight. NASA currently plans a second qualification test with dynamic loads after the next flight. The Panel believes that two or more dynamic tests in full-scale, full-duration firings with structural deformations to simulate launch and flight loads should be completed before flight. Recognizing that the number of full-scale, full-duration tests of necessity will be small, we have emphasized testing to design limits, testing with imposed flaws, and forecasting test results to help develop confidence in the reliability of the new designs.

Mr. Chairman, that concludes my testimony except to state for the record that our Panel is impressed with the dedication and hard work of the redesign team. They deserve the nation's praise for diligent efforts under stressful conditions.

I will be happy to try to answer your questions.

ATTACHMENT A: Panel Members

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
2101 Constitution Avenue Washington, D.C. 20418

COMMITTEE ON NASA SCIENTIFIC
AND TECHNOLOGICAL PROGRAM REVIEWS
Panel on Redesign of Space Shuttle
Solid Rocket Booster

OFFICE LOCATION:
JOSEPH HENRY BUILDING
21ST STREET AND
PENNSYLVANIA AVENUE, N.W.

Panel Members

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* Member, National Academy of Engineering

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ATTACHMENT B: Statement of Task

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
2101 Constitution Avenue Washington, D.C. 20418

COMMITTEE ON NASA SCIENTIFIC
AND TECHNOLOGICAL PROGRAM REVIEWS
Panel on Redesign of Space Shuttle
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PENNSYLVANIA AVENUE, N.W.

STATEMENT OF TASK

The Panel will provide technical assistance to the National Aeronautics and Space Administration by reviewing and evaluating the work of the NASA/industry team that is redesigning the solid rocket booster used in the space transportation system. To fulfill this responsibility, the Panel will meet as needed with NASA and industry personnel or other members of the scientific and engineering community. In addition, the Panel will participate in NASA's scheduled formal reviews, including but not limited to the following:

Preliminary Design Review
Test Plan Review
Certification Test Requirements Review
Critical Design Review
Design Certification Review/Full Scale Test Results
Flight Readiness Review
Flight Performance Review and Inspection

In connection with the flight readiness and performance reviews, which include all systems that comprise the space transportation system, the Panel will focus its attention on the solid rocket booster. Also in this connection, the Panel will not exercise oversight responsibilities or make recommendations regarding any operational decision.

Following each formal review, the Panel will provide its evaluation to the Administrator of NASA in the form of a short letter report and oral briefing. The Panel will also prepare a final report that may contain a description of the overall process of designing and implementing an improved booster; updates of activities of the NASA/industry team subsequent to the preparation of the specific evaluations; and a summary and update of the findings, conclusions, and recommendations of the committee as appropriate.

The project responds to a recommendation of the Presidential Commission on the Space Shuttle Challenger Accident and is funded by the National Aeronautics and Space Administration.

ATTACHMENT C: Letter Report No. 1

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
2101 Constitution Avenue Washington, D.C. 20418

COMMITTEE ON NASA SCIENTIFIC
AND TECHNOLOGICAL PROGRAM REVIEWS

OFFICE LOCATION
JOSEPH HENRY BUILDING
21ST STREET AND
PENNSYLVANIA AVENUE, N.W.

August 1, 1986

The Honorable James C. Fletcher
Administrator
National Aeronautics & Space Administration
400 Maryland Avenue, S.W., Room 7137
Washington, DC 20546

Dear Jim:

Based on an initial appraisal of the objectives and focus of the program to redesign the SRB, I am pleased to provide this interim report containing observations, conclusions, and recommendations of the NRC Panel for the Technical Evaluation of the Redesign of the Space Shuttle Solid Rocket Booster.

Background

Beginning with its formation in early June 1986, the Panel has had introductory briefings by personnel of NASA Headquarters, Marshall Space Flight Center (MSFC), and Morton Thiokol, Inc., on the current design and manufacture of the solid rocket motor (SRM), the mission 51-L accident, and preliminary plans for the redesign. We have had more detailed briefings from and discussions with personnel of Rockwell International, Thiokol, and NASA/MSFC on the structural loads and dynamics of the total assembled shuttle and the resultant loads on the SRM, as well as briefings from personnel of United Technologies Chemical Systems Division, Aerojet Strategic Propulsion Company, and Hercules Aerospace Company on alternative solid rocket designs and alternative joint and seal designs. We have toured the Thiokol manufacturing and test facilities and engaged in many detailed technical discussions with Thiokol personnel on design and testing of proposed future SRB designs. We have also been informed by Air Force personnel about the results of their investigation of the recent accident involving the Titan solid rocket motor.

Focus of the SRB Redesign Program

In addressing its charge to provide a technical evaluation of the redesign effort, the Panel is aware of four interdependent factors that influence the program. They are safety, time, costs, and performance. Above all, safety is the prime consideration. The critical national need for the launch capability of the Shuttle makes time a close second. Consequently, we recognize that NASA is initially concentrating on those redesign approaches that will provide the required margins of safety with maximum use of existing facilities, hardware, and components. In addition to engineering design, the Panel is also reviewing the program for testing and verification of safe performance of new designs, selection and specification of materials, and quality assurance or control.

In parallel with this initial approach, the Panel intends to address alternative designs for the SRM to raise the level of not only safety and economy, but also performance.

Design Specifications and Requirements

We understand that the specifications and requirements for redesign of the SRM are being completely reexamined. We have noted differences between NASA/MSFC and Thiokol personnel on this subject, particularly on the application of past specifications and requirements for the redesign. Great care and prompt action should be taken to eliminate these differences and misunderstandings. We conclude that the redesign process cannot proceed successfully unless and until all parties agree to and understand the meaning of specifications and requirements placed on the performance of the new SRB.

Joints between Motor Segments

While the Panel agrees with the Presidential Commission that faulty design of the pressure seal, compounded by the cold temperature at launch and dynamic joint rotation, is the most probable cause of a blow-by of the two O-ring seals in the aft field joint of one SRB, the ensuing events which resulted ultimately in the loss of the shuttle (almost 60 seconds later) are much less clear. It has been hypothesized that sealing was reestablished by a plug of material which was dislodged later, possibly during conditions of high dynamic pressure including wind shear, leading to melting of the case metal in and adjacent to the joint by hot gas. The details, however, remain uncertain and this uncertainty is very important for the redesign.

All failure modes must be examined, and all potential weaknesses in the design of the motor should be eliminated or reduced to the extent possible. For example, the probability of debonding of insulation from the metal case should be minimized as should the probability of the introduction of moisture into the case where corrosion of metal parts or degradation of performance of the elastomeric parts can occur. We recommend that NASA consider using existing SRM cases to perform tests on the joint to investigate the mode of failure of mission 51-L to assure that our understanding of the weaknesses in the original design is correct. The tests should be designed to investigate alternative modes of failure and to duplicate the failure of the 51-L joint.

Based on its work to date, the Panel recommends that each of the following be addressed in the new design: joint rotation from all sources; O-ring materials; O-ring and groove design; verification of O-ring seating; insulation at the joint, considering the potential for gas flow in the gaps; asymmetries in gas circulation in the bore, gaps between segments, and nozzle from various causes; the bond between the metal case and insulation, and the role and properties of putty or alternative means for protecting the O-rings from exposure to hot gases. The previous design employing two pressure-activated O-rings was adopted in response to the requirement that the seal be both redundant and verifiable. The redesign program focuses on joint designs that employ a double clevis arrangement to reduce rotation and either two or three O-ring seals, among other things. It is not clear to the Panel that two pressure-activated O-rings always provide redundancy.

In these early stages of the redesign program, it is important to maintain consideration of a diversity of designs, including both modifications of the proposed double-clevis joint, and simpler alternatives such as reinforcing the case walls to reduce rotation. An array of alternatives should be investigated and carried through the redesign process as far as is practical.

Additional discussions of joint redesign are scheduled for an early August meeting of the Panel.

The Nozzle

The nozzle of the SRM has experienced serious problems in the nozzle-to-case joint and the ablating material in the nozzle itself. Work to correct these problems has been underway for several years but much more needs to be done. Alternative designs in which joint rotation tends to close gaps between parts rather than to open the gaps (as in previous shuttle SRM designs) appear to be inherently safer. We recommend that NASA include such designs in the redesign program.

Materials

Materials have always posed serious challenges in solid propulsion rocket design and new problems are emerging. Clearly the putty used heretofore in the SRB is one such material. The expected and actual performance of the putty seem quite unclear. Designs are being considered that do not require its use.

Results of the investigation of the Titan accident suggests a new materials problem, a potentially erosive interaction between molten alumina and the steel case, that accentuates the need to avoid exposing steel casing to propellant gases. We recommend that this phenomenon be researched vigorously because of its potential importance for the safe design of future solid rocket motors. We also recommend that NASA review its requirements and specifications for assurance of the adequacy of bonds in light of this recent development.

There is also a great dependence on bonded materials without techniques for assured inspection of bonds. Progress is currently being made in non-destructive inspection techniques, but they still leave great room for improvement. We recommend that NASA carefully monitor development of techniques for non-destructive testing of bonds being carried out by the Air Force and apply the techniques, if appropriate.

It may also be anticipated that asbestos, currently incorporated into the inhibitor material for the SRM, may not be available in the future. We recommend that NASA consider developing and qualifying asbestos-free insulating materials for the SRM within the current redesign effort to avoid a subsequent requalification when asbestos is no longer available.

Quality control procedures for materials supplied by vendors appear to have depended largely on the ability of product specifications to define adequately and completely the material to be supplied, backed up by the qualification of vendors, at least for critical items. This procedure is not adequate for many materials, polymers in particular being notorious for their inability to be completely described by product specification. The system should be strengthened for most components by: qualifying vendors' vendors (and in a few cases, such as the O-rings, vendors' vendors' vendors) and imposing a process "freeze" on the part of vendors (and vendors' vendors, etc.) with requalification required for any process change. We recommend that NASA review the experience of the military with control and surveillance of materials for its solid rocket motors and where applicable adapt that experience to the SRM program.

Testing

The fact that a solid fuel rocket can never truly be tested except in flight places unusual emphasis on adequate subscale and full scale testing with appropriate simulations and statistical analysis. It is our first impression that the proposed test program at best only meets a minimal requirement; it is clearly success oriented. The Panel needs more information on the detailed tests to be conducted before we can reach an opinion about the feasibility of meeting the current test schedule, but it appears clear that the planned sample size may not be adequate for testing all specified requirements. An opportunity exists, however, to reduce some limit testing through design choices, for example using heaters at the joints would obviate the need to test joints at cold temperatures.

The special issue of vertical vs. horizontal testing is still open and will be further discussed when the Panel meets in early August. Dynamic performance of the shuttle system and its effects on the SRB need both testing and analysis. The critical issue is the extent to which the actual dynamic conditions of launch and flight can be simulated in a vertical test stand. A corollary issue is whether vertical testing provides enough additional data--or indeed as much useful data--as to be worth the additional cost. For equivalent expenditures and time, a larger number of horizontal tests can be performed.

Sincerely,

H. Guyford Stever by

H. Guyford Stever
Chairman
Panel for the Technical Evaluation of
  the Redesign of the Space Shuttle
  Solid Rocket Booster

c: Adm. Richard H. Truly

ATTACHMENT D: Letter Report No. 2

NATIONAL RESEARCH COUNCIL

COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS

2101 Constitution Avenue Washington, D.C. 20418

COMMITTEE ON NASA SCIENTIFIC
AND TECHNOLOGICAL PROGRAM REVIEWS

Panel on Redesign of Space Shuttle
Solid Rocket Booster

OFFICE LOCATION
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October 10, 1986

The Honorable James C. Fletcher
Administrator
National Aeronautics & Space Administration
400 Maryland Avenue, S.W., Room 7137
Washington, DC 20546

Dear Jim:

I am pleased to submit herewith the second interim report of the National Research Council Panel for the Technical Evaluation of the Redesign of the Space Shuttle Solid Rocket Booster. The purpose of this letter is to provide an independent technical evaluation of the progress of the redesign program thus far.

Background

During August and September, the Panel formally met twice with personnel of NASA Headquarters, Marshall Space Flight Center, and Morton Thiokol, Inc. The Panel also conducted a visit to the Kennedy Space Flight Center, where we inspected recovered parts of Mission 51-L, were briefed on techniques for recovering spent solid rocket boosters (SRB) from the ocean, and witnessed a demonstration of the preparation of booster segments for mating. Members of the Panel visited the Rocket Propulsion Laboratory at Edwards Air Force Base to inspect the dormant vertical test stands there, and some attended the meeting of the Program Requirements Review Board. Members also revisited Morton Thiokol for more thorough exchanges with the company's engineering personnel.

Perspective on the Redesign Program

The redesign effort has progressed greatly in these two months, principally refining in detail the earlier redesign ideas for the case field joint, igniter, and nozzle joints, as well as for changes of the nozzle linings. The focus of the effort is still on designs that will permit the use of booster rocket case forgings ordered previously. If this approach is successful, i.e., if the test program succeeds and the level of safety is judged acceptable, the Shuttle flight program can resume at the earliest time. The Panel concludes that the chances of success of this approach are sufficiently good that it should be pursued.

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

The New Baseline Design

The baseline design of the new case field joint incorporates a capture feature that engages the inside leg of the clevis to restrict relative motion between the tang and clevis. We concur that the design will significantly constrain the motion.

There are however a number of practical aspects of the design that are uncertain and of concern. The increased rigidity of the joint will cause additional bending stresses to be carried by the case membrane on either side of the joint; the additional stresses need to be fully understood. The capture feature may make mating and demating the segments more difficult than in the past. The multiplicity of additional seals in the new design (an adhesive bond in the insulation, the O-ring on the capture feature, and the metal-to-metal interference fit of the capture feature) will make it difficult to qualify and verify by test the primary and secondary pressure seals, which by definition are the two O-rings between the clevis leg and tang. While the bond between facing insulators is not intended to qualify as a pressure seal, it will normally prevent exposure and evaluation of the metal joint during qualification tests (as the putty did in previous tests and flights). The new design imposes more stringent dimensional tolerances and the effects of reuse in meeting the tolerances remain to be determined. These and other uncertainties must be resolved through a vigorous test and engineering program.

Regarding design of the insulation in the gap between case segments, the Panel notes that the baseline bonded insulator designs, while advantageous for protecting the metal joint and insulator-to-case bond, may also pose problems with assembly and demating. Alternatively, an unvented joint may be obtained without using an adhesive by employing unbonded insulating materials to fill the gap between facing inhibitors. The inserts would have to be compressed during assembly and be sufficiently resilient to accommodate the expansion of the gap that occurs at ignition.

The program has also considered and will test a vented design employing a labyrinthine gap between ablative surfaces that causes combustion gases to travel a longer distance before reaching the joint. This design as presented may prevent hot combustion gases from impinging on the pressure seal components. Alternative approaches to a vented design may also be practical, including those intended to assure that any gases reaching the joint have cooled to acceptable temperatures. Such designs, which have not been considered in the program, could, for example, employ porous ablative materials in the gaps between segments to act as thermal barriers. The structure could incorporate a volume or reservoir of relatively cool, stagnant combustion gases between the mated insulating segments upstream of and in series with the first seal along a potential leak path. This volume could be filled with a porous ablative material that would physically inhibit gas exchange and absorb the sensible heat that enters the reservoir. This approach could also, of course, be used with an unvented insulator design adding further to its overall reliability. In either case, such a reservoir should be designed to dampen acoustic oscillations in the gap.

Pending the results of full scale tests, the Panel regards both vented and unvented insulator designs as potentially satisfactory. Therefore, the Panel recommends that both vented and unvented designs be pursued in parallel in the development effort. This recommendation is based on serious concern about the validity and scope of the testing of the baseline (bonded) design.

The Panel urges that a final decision on the design of the insulation between segments be delayed until:

a) the performance of both unvented and vented designs has been evaluated in full diameter, full duration tests; and

b) the feasibility of assembling and disassembling the unvented design is evaluated.

Tests of potential O-ring materials performed to date have resulted in the identification of three elastomers that hold promise for use in field joints. Unfortunately, because end item specifications are not generally effective for controlling elastomer formulations, uncertainties may arise regarding the exact composition of the tested materials. To avoid future problems, we strongly recommend that any candidate materials be thoroughly defined, in cooperation with their suppliers, in formal advance specifications. As described in my letter of August 1st, we believe that the best approach would include specifications, even for test materials, by product, process, and supplier at all levels and to "freeze" these specifications. These should supplement performance specifications for O-ring materials.

The O-ring materials being considered retain the capacity to follow the gap opening at low temperatures. In light of reduced gap openings and improved cold-temperature resilience, the use of supplementary heaters should not be necessary. It seems prudent, however, to continue to develop the heaters as a precaution in the event that these materials cannot be used for some reason.

The Panel also notes that the new O-ring materials are intended to be used in the case factory joints, which will not otherwise be changed. The factory joint is fundamentally different from the field joint. We do not understand the rationale for changing the O-ring material in the factory joint. It is also not clear to us why the program continues to use spliced O-rings. While an acceptable O-ring can be made either by splicing or by one-piece precision molding, good industrial practice avoids splices.

The Shuttle solid rocket motor (SRM) has frequently experienced "minor" debonding between the case and insulation. Reliability of case-to-insulation bonds can be improved if procedures for removing grease from the metal can be enhanced or substitutes found for the grease that is used as protection against rust. We recommend first that recent improvements in the technology for testing bonds nondestructively be exploited fully and second that any detectable debonds be appropriately repaired before flight.

The Panel still has under consideration design issues in the case-to-nozzle joint, joints within the nozzle, and the igniter. These elements of the SRM are as important for the success of the redesign as the case field joint. The baseline design of the nozzle introduces many more bolt holes, leak check ports, and pressure seals. Reliability could be reduced by some of these changes.

The Test Program

Much progress has been made in laying out the program of tests, which has begun. Significant results, for example from the Joint Environment Simulation test, have already been obtained, but there is still much to do. The success of the redesign effort rests on the test program.

The Marshall and Johnson teams and their contractors have briefed us on the potential role of a full-scale vertical test firing, including structural dynamics, in the test program. They have made the point that a variety of horizontal firings and other tests can, in fact, verify the essential features of the new design. It is further argued that a vertical firing on a test stand will not reproduce the precise conditions experienced during launch and flight. The design team has recommended against incorporating a vertical firing in the program. The Panel notes that the desirability of vertical testing has been evaluated by NASA and concurs that horizontal testing can be appropriate for this situation. We conclude however that to be comprehensive, the totality of the test program must include simulation of the dynamics of launch and flight.

Design of the test program to simulate these effects should take into consideration how loads are actually transferred from the solid rocket booster (SRB) to the External Tank through both fore and aft struts, the dynamic conditions known as "twang", and vectoring of the nozzle under flight conditions. Some members of the Panel believe that this is best accomplished by constructing a new full scale horizontal test stand both to be used as an alternate to the current facility and to provide a facility suitable for conducting dynamic tests of the structure, nozzle, seals, etc. The new test stand should be constructed so that loads can be taken out through realistic struts, a displacement to start the twang oscillation can be imposed, and a complete simulation of nozzle vectoring can be obtained.

We recommend the creation of an additional horizontal test stand to accommodate and test full-scale motors both to provide the capability of performing more tests and to reduce the risk to the program should a catastrophic failure occur during a test. We also believe that a second Joint Environment Simulator test stand and associated hardware is warranted and should be established.

Regarding other aspects of the test program, the Panel offers the following comments and recommendations:

a) The current test schedule envisions only one full scale, full duration test of the new nozzle that incorporates all the changes of the redesign. We recommend additional full scale, full duration testing to assure that the various elements of the design, including ablative material and additional pressure seals and leak check ports, operate as expected over the range of conditions imposed by the requirements. In our opinion, a single full scale, full duration static test of the redesigned nozzle (prior to the first flight) is simply not sufficient. The number of tests required depends on the results of the tests and professional judgment.

b) We endorse whole-heartedly the concept of testing articles that have incorporated inflicted flaws.

c) We believe the testing program should be designed to distinguish between alternative designs regarding performance. For example, both vented and unvented joint insulation designs should be tested in regimes in which the alternatives could be expected to behave differently.

d) In light of the specification that Shuttle components must be acceptable after five years' storage before flight, a test and surveillance program should be established that will ensure satisfactory performance of components, such as O-rings, prior to use. Representative samples of O-ring materials applicable to each assembled SRB should be stored in a compressed state in an appropriate fixture to simulate the environment of the assembled O-rings. These materials should be tested for dynamic resilience as a final verification before launch.

e) The tests should be fully instrumented so that incipient failure modes can be identified.

We plan to conduct a continuing review of the test program, including instrumentation needs and the simulation of dynamic conditions of launch and flight, and the results over the next several months. Our next interim report will address the test plan in detail. We also will continue to review aspects of the design including assembly and disassembly of field joints and reuse.

Alternative Design Considerations

The alternative designs being considered by NASA meet the constraint of using the case forgings that have already been ordered. The alternatives employ various designs for the insulation in the gap between segments, such as the labyrinthine vented joint or the cooler-gas vented joint. At least one such alternative will be included in the test program; we hope that several of the more promising candidates can be pursued through testing.

Alternatives to the baseline designs of the metal parts of both the case joint and the case-to-nozzle joint also exist which have not been thoroughly explored on the grounds that they will not be compatible with the forgings which have already been ordered. We recognize the importance to the nation of returning the Space Shuttle to service without unnecessary delays. If, however, the design process were not constrained by the forgings, we believe that more basic alternatives to the baseline design would probably be preferred once thoroughly analyzed.

For example, it is possible to design both case and case-to-nozzle joints, without capture features, that tend to rotate closed upon pressurization or not to rotate at all. Similarly, modifications of the simple tang-and-clevis joint, such as by changing the dimensions of the parts, might reduce the rotation substantially. The concept of a joint that rotates closed or does not rotate at all might be implemented for the case joint either with bolted flanges, as suggested by the group at NASA/Langley Research Center, or with a pinned tang-clevis joint. With the pin concept, the tang-clevis joint would have to be drawn into a smaller radius than the case cylinder. This approach might be accommodated by the current billets. Using either technique might result in the reduction or elimination of joint rotation by design rather than mechanically by using a capture feature.

We strongly recommend that NASA maintain a program to explore and develop original, possibly quite different designs for the next generation of SRB in parallel with the current redesign effort and for the contingency that the baseline design may not offer sufficiently good performance and margin of safety. In particular, an alternative SRB should take advantage of designs that are insensitive to or will benefit from the structural deformations that occur after ignition.

Requirements, Specifications, and Institutional Relationships

There does not appear to be a very clear separation of organizational responsibility for defining requirements or specifications and designing the hardware. The Project Office at Marshall not only develops requirements and reviews and approves designs, but also is deeply involved in the detailed design process. Thus it can happen that the design team can also approve waivers to the basic requirements. We conclude that a clear separation of the responsibilities for specifying requirements and implementing a design to meet those requirements would allow designers greater flexibility to consider alternative solutions and assure a more independent evaluation of the design in light of requirements.

Several issues were raised by Panel members regarding specific requirements for the redesign during the Program Requirements Review Board meeting on August 26-27. Of these, we include the following points here:

a) We understand that the baseline design may not satisfy all the requirements. Some requirements, in fact, are actually design specifications. It appears to us that NASA may be setting itself up for new waivers as a consequence. We recommend that NASA carefully reconsider the design requirements to assure that unnecessary specifications are not incorporated that will necessarily result in waivers.

b) A number of different types of safety factors are quantitatively imposed by the requirements. However, they are only loosely defined in terms of what specifically should be measured, the method of measurement, and the details of the method of calculating safety factors.

c) There seem to be different interpretations of terms such as factor of safety, redundant, verifiable, etc. We believe that it is important that concise, quantifiable definitions be prepared and used.

Summary

In summary, we have concluded that the chances for success with the current approach to case field joint redesign are sufficiently good that it should be pursued. This choice is the consequence of the understandable desire to use existing hardware to the greatest extent possible, including new case forgings previously ordered. The baseline case field joint will be difficult to evaluate by test. Implementation of alternative designs for metal joints, which may prove to have significant advantages, would take considerably longer but should be pursued in parallel with the current redesign program.

The success of the redesign effort depends on the test program. We believe that the planned test program requires significant augmentation with additional facilities and tests. It need not, however, include a full scale, full duration vertical test provided the static and dynamic loads of launch and flight, separately and in combination, are appropriately simulated elsewhere in the program.

Sincerely,

Guy

H. Guyford Stever
Chairman
Panel for the Technical Evaluation of
the Redesign of the Space Shuttle
Solid Rocket Booster

c: Adm. Richard H. Truly
Panel Members

ATTACHMENT E: Letter Report No. 3

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
2101 Constitution Avenue Washington D C 20418

COMMITTEE ON NASA SCIENTIFIC
AND TECHNOLOGICAL PROGRAM REVIEWS
Panel on Redesign of Space Shuttle
Solid Rocket Booster

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January 15, 1987

The Honorable James C. Fletcher
Administrator
National Aeronautics & Space Administration
400 Maryland Avenue, S.W., Room 7137
Washington, DC 20546

Dear Jim:

I am pleased to submit herewith the third interim report of the National Research Council's Panel for the Technical Evaluation of the Redesign of the Space Shuttle Solid Rocket Booster. The redesign effort is currently in transition from a period devoted to creating the so-called baseline design using analytical techniques to one concentrating on testing the concepts and hardware. The purpose of this letter is to critique the program at this stage.

Background

Since early October, the Panel has met formally three times. In addition, groups of our members have participated in a number of technical meetings with personnel from Marshall Space Flight Center and Morton Thiokol, Inc. Members have visited Latrobe Steel Company and the Ladish Company to review capabilities for producing steel cases for the motor and the U.S. Air Force Space Command to discuss methods of nondestructive evaluation of insulation bonds, as well as other aspects of the redesign that might benefit from the Titan SRM program. We have also kept up to date on the progress of the contractors who are developing concepts for a Block II motor.

Current Status

NASA's goal is to return a safe and reliable Shuttle to service at the earliest possible date. To meet the goal, the NASA team has chosen a baseline design and is in the process of organizing and implementing a testing program to verify that the design meets the requirements of the program. The redesign baseline is aimed at correcting the causes that contributed to the failure as well as other elements of the original design that showed signs of trouble in flight or that do not meet the new design criteria. Most decisions have been made as to which features need complete redesign, which need modification, and which can remain the same as before. Only those changes considered mandatory for the next flight are being made.

Only if the verification program goes very well can NASA's schedule be met; care must be exercised in the ground-test program to assure that the design is adequately demonstrated. Morton Thiokol is well started on this program and should be strongly supported in its pursuit.

As discussed in an earlier report of our Panel, however, the test program is success-oriented. By this, we mean that the schedule for the program reflects an assumption that each test will produce results that are expected and understood; there is little room in the schedule for modifying the design if this does not prove to be the case. Preliminary tests have already produced results that were not anticipated. For example, O-ring materials with better low temperature resilience were found to deteriorate when tested after extended exposure to the rust-inhibiting grease, with the result that the baseline design now uses the original fluoropolymer O-rings with heaters to maintain an appropriate temperature.

It is prudent, therefore, to plan for contingencies, particularly for those elements of the design for which substantial uncertainties remain. If an aspect of the design is shown not to meet safety objectives, an alternative should be available to carry the program forward. In some areas the program has incorporated alternatives to the baseline design. Nonetheless, we are concerned that valuable time would be lost should it become necessary to turn to one or more of the alternatives as a consequence of something learned from the test program. Further, now that the NASA/Thiokol redesign team is nearing the completion of the selection of the baseline design, it should be able to increase its efforts on preparing for contingencies. We recommend, therefore, that NASA strengthen its contingency plans for incorporating alternatives into the program.

Aspects of the design that warrant more contingency planning include the case field joint, the case-to-nozzle joint, and configurations of the insulation at both the case and case-to-nozzle joints. Materials for which contingencies should be in the program include the ablative materials in the nozzle, O-rings, and the rust inhibitor. Options currently in the program are limited. For example:

- The Panel still believes that contingency planning should include the design, fabrication, and testing of a case field joint that closes under pressurization. We understand that such a design can be obtained without changing the configuration of the existing forgings, but the first step in this process is to order the appropriate forgings, which has not been done.

- Currently, there is no real alternative in the program for the baseline design of the case-to-nozzle joint, which incorporates a large number of new bolts and bolt holes, hence complex stress patterns and potential leak paths. We consider the lack of an alternative to be serious since the joint is critical for safety, few tests of the final configuration are planned, and they occur late in the test program. We recommend that alternatives be established and special emphasis be placed on early, meaningful tests of the design.

- The baseline design of insulation at the field case joint incorporates an adhesive bond between opposite sides of the gap. Two variations of this unvented design are being studied, called the J-seal and U-seal. The backup design, a vented configuration, will be evaluated in subscale tests and a full-duration, full-scale test firing, but it is not being carried forward on a schedule that would permit its inclusion in the program without a delay. The baseline design of the case-to-nozzle joint also incorporates an adhesive bond. NASA should anticipate that the details of the insulation design at both joints, whether unvented or vented, will continue to change and we recommend that the Agency provide for additional insulation tooling to enhance the flexibility of the program.

Significant changes in estimates of loads in the SRB and both of its interfaces with the External Tank have recently been reported to us. In light of these changes and the crack in an aft skirt during a recent structural test, we recommend that stress analyses of the booster and its parts be carefully reviewed and, as appropriate, calculated again using the best data and most up-to-date models.

The Panel has additional technical comments and recommendations on the current design and testing program, which are presented later in this report.

Perspective on the Future

Not all the changes that the engineering team would like to make in the solid rocket motor will be made before the next launch. By directive from NASA headquarters, the redesign effort is focussing on identifying those changes essential for adequate safety or reliability for the next flight. The purpose is to avoid a dilution of effort on the mandatory changes, which could delay the Shuttle's return to service. We concur with this approach in principle.

Beyond the changes deemed mandatory for the next flight, however, additional changes may also be needed further to enhance its safety and improve its reliability, performance, and cost effectiveness. The solid rocket booster, no less than other technological products, should continually be improved by changes driven by the results of tests and data gathered during use. It is our impression that the ongoing technological program that supported improvements in the reliability of the Shuttle solid rocket motor before the accident was limited compared with that for improving performance.

We recommend, therefore, that NASA establish and maintain a directed program for continued evaluation and improvement in reliability after flights are resumed, including all of the following: use of flight instrumentation for diagnostics throughout the flight program; continuing evaluation of flight results and recovered hardware; continuing ground testing to understand and, as necessary, improve the hardware promptly; and preplanned block changes to the flight hardware to provide opportunities for incorporating desired improvements.

In the long term completely new designs, possibly radically different from the current one, may be preferred. The nation's manned space flight program cannot afford to continue to rely on older technology indefinitely into the future. Consequently, we believe that NASA should vigorously pursue a program to develop the next and future generations of motors for use in the space transportation system. The studies of alternative concepts for the SRM that NASA commissioned in 1986 is a commendable step in this direction.

The program outlined above--including near-term changes to meet immediate goals, intermediate-term changes for product improvement, and long-term changes to incorporate substantially improved technology--can only be accomplished with the support of research and development. Not all of the required R&D can be accomplished within the current recovery program, so it may be necessary for NASA to include appropriate activities elsewhere within its programs.

Additional Conclusions and Recommendations on Technical Issues

The Case Joint. We are concerned that the baseline design may not readily allow for reworking or inspection of the hidden surfaces of the capture feature. We conclude that this problem requires special attention since it could be sufficiently serious to prohibit reuse of the case segments if the finishes and absence of corrosion cannot be satisfactorily verified.

The baseline design now specifies fluoropolymer O-rings lubricated with HD-2 grease, as used in all the previous flights, with heaters to maintain the O-rings at the temperature (75°F) required to assure a satisfactory seal. The Panel is concerned with this development because of added complexities and potential reliability problems associated with the heaters. For example, overheating the joints could adversely affect adhesive bonds, which are invariably weakened at elevated temperatures, or the properties of components, such as O-rings or grease, in unpredictable ways. It seems likely that an alternative grease can be found or formulated that will both have acceptable corrosion protective properties and not interact adversely with the silicone or nitrile O-ring materials. We recommend that a priority effort be aggressively pursued to improve understanding of the properties of these materials and to develop a better combination of O-rings and grease for use as soon as possible.

The redesign team has considered two concepts for the design of insulation between adjacent segments, vented and unvented, and has selected the latter as the baseline approach. In this concept, a properly functioning insulation would shield the metal joint from combustion gases. Should a leak occur in the interface, however, the joint has been designed to inhibit further propagation of the high-pressure gases through the O-ring seals. The small joint rotation anticipated with the capture feature, interference metal fit between the clevis leg and capture feature, and three O-rings are configured to provide redundant protection in sealing against various upstream leak scenarios. Because the unvented insulation design, if successful, will shield the O-rings from exposure to pressure on hot gases, tests with imposed flaws are particularly important for determining the adequacy of the design of the seals.

In response to the requirement that pressure seals be verified, the program envisions testing the O-rings after assembly by applying pressure through ports. Applying an inappropriate pressure could damage the insulation or bond line between case segments. We remain concerned with this issue and expect to pursue it further as verification procedures are developed.

The Nozzle. The Panel currently perceives that uncertainties in the design and hence risk to the program are now greater in the area of the case-to-nozzle joint and for the other aspects of the nozzle than in the case field joints. Unlike many of the issues associated with the field joints that can be resolved to a reasonable level of confidence with subscale or short duration tests, several of the critical questions on the nozzle design can only be really answered with full scale, full duration testing.

Mating and sealing the segments of insulation at the case-to-nozzle joint is a very different proposition from that at the case field joint. During assembly of the case-to-nozzle joint, the insulation on the fixed nozzle housing must slide for several inches over the insulation on the aft dome, complicating design of the insulation and adhesive for an unvented design. Here the method of sealing of the mating segments of insulation is still open to question. We recommend continued modelling and subscale testing of alternatives that insure that only cooled, low momentum gas can reach the O-rings in the event of a leak in the seal between mating segments of insulation at the joint.

The general requirement for pressure seals to be redundant and verifiable is being applied in the current baseline design to all of the internal nozzle seals. This requires the addition of a second O-ring in many cases and the addition of ports to verify and seat the seals. The second O-rings are intended to enhance reliability, but overall reliability may not be increased because of the penetrations of the nozzle added for the purpose of verifying the O-rings.

Tests of the nozzle ablative materials will not be performed until late in the verification program. Marginal or unsatisfactory performance in these tests could severely affect the schedule for the next launch. There are no backups in the program for design of the layup of ablative materials in the nozzle. Given the empirical nature of the technology and its unpredicted behavior in past flights, we recommend that, in addition to the planned full scale, full duration tests of the nozzle, the redesign team undertake a series of subscale, long duration firings to evaluate the conceptual basis and materials technology for the redesign of the ablatives.

The Test and Verification Program. As indicated in an earlier report, we regard the proof of the redesign to depend on the results of the program to test it and verify that it meets the requirements of the system. The test and verification program is just getting underway and is still evolving. Some preliminary tests have been conducted, but firings with new case hardware are not expected before March, 1987. The test program appears to be somewhat constrained by the ability of the support organizations to provide test articles, instrumentation, etc. We intend to follow the development and progress of the test program carefully. Meanwhile, we make the following observations and recommendations.

While we continue to see progress in the definition of the total test program, it is difficult to relate the objectives of each of the numerous tests to specific design requirements or to develop a sense of the coherence of the test program in terms of its support of the development effort. Clear plans that relate each test to specific design requirements or to the development of specific components or subsystems would help to assure coherence of the total effort.

For NASA to accept a design as safe and reliable, we believe that the Agency should be convinced that it understands how the design will behave throughout the range of conditions that the SRB is intended to experience. Recognizing that it may not be practical to test the design throughout the range of conditions, NASA plans to verify some aspects of the design by analysis rather than by test. Verification by analysis relies on the use of analytical and computational models, so to incorporate this technique requires that the models be validated by experiment. We recommend that tests within the current program also be instrumented specifically to validate the models.

The verification program is aimed at determining if the design meets requirements, but it should also have the value of enhancing confidence that the redesign team understands how the design works. The Presidential Commission concluded that neither NASA nor its contractors understood the previous design very well. To assure better understanding, we recommend that before each major test in the verification and qualification program the redesign team make explicit analytical predictions of the performance of the test article; the results of each test should be examined in light of the predictions and any discrepancies fully explained. Criteria for successful verification in each test should also be established *a priori* to assure the objectivity of the test program. These are common engineering practices and are applicable to the Shuttle program.

The Panel expressed concern in its last report over the limited capacity of full scale test facilities. We believe that the addition of another full scale, full duration firing test stand capable of simulating dynamic loads is a major step forward in that regard. Conditions that should be simulated on the stand include launch loads and the most severe flight conditions. We have recently learned, however, that the new facility may be limited in its capability to simulate these loads and further that estimates of the maximum loads are being revised downward. We are concerned both about how well the loads are understood and the adequacy of the new facility. We recommend that the design of the stand be carefully reviewed to assure that the test results will be most useful.

NASA apparently has concluded that another Joint Environment Simulator (JES) test stand is not needed because additional test hardware will allow more frequent tests on the existing stand. Each of the three JES tests conducted to date (using case joints of the original design) yielded results that were not predicted by prior analyses. For example, tests have shown that the extent of joint gap opening depends on whether pressurized gases reach the region between the clevis leg and the tang. The JES-1B test showed that the silicone O-rings cannot be used with the current grease. JES tests also revealed that pressurized gases can leak past the seals significantly before the occurrence of the peak pressure or peak gap opening. These tests have provided extremely valuable data and insight into the behavior of joints. They also supply data to improve the analytical models. We concur that additional test hardware for use in the current JES and the related Transient Pressure Test Article will enhance the full scale test capability. If the rate of timely testing in these facilities is not sufficiently enhanced by addition of test hardware, we recommend that NASA reconsider its decision not to build an additional stand.

At this writing, NASA has not formally approved the firings of Qualification Motors 7 and 8 before flight. In view of the number of features of the new design that depend critically on full scale, full duration testing, the Panel recommends that these be approved and incorporated into the test program immediately. Furthermore, the Panel believes that the dynamic tests in full scale, full duration firings with structural deformations to simulate launch and flight loads must be completed before flight.

Finally, we are grateful for the cooperation that we have received from NASA, Thiokol, and other personnel. The redesign team deserves praise for its dedication and hard work.

On behalf of the Panel, I remain,

Sincerely,

Guy

H. Guyford Stever
Chairman
Panel for the Technical Evaluation
of the Redesign of the Space
Shuttle Solid Rocket Booster

c: Adm. Richard H. Truly
Panel Members

Mr. **Nelson**. Dr. Stever, you deserve credit and commendation for obviously very thorough and dedicated work, as evidenced by your presentation here. And thank goodness that there are folks like you and Dr. David and others that are all, after this tragedy, coming in now and trying to help get this system back where it's flying again.

You mentioned about case growth. Do you think NASA understands what is going on with the case growth?

Mr. **Stever**. Yes.

Mr. **Nelson**. Excuse me just one second. There is a vote on, and I will recess the committee and we will just come right back, and I will have Dr. Stever answer that one question, and then we will go on.

Mr. **Stever**. They have made tests. They believe that the case growth—they do understand it better. It appears that with any pressurization, the case does grow in the first perhaps three pressurizations and then it ceases, and that's to be expected in the kind of metals they have.

On the other hand, it's—case growth is something that has to be watched all through the testing program, all through the flight program, and the reuse of those things. But I do think that they have as good surveillance of that as they can have.

Mr. **Nelson**. Okay. We will recess the committee. There is a live vote on, and we will resume shortly.

[Recess.]

Mr. **Nelson**. All right, let's resume.

Dr. David, if you would come on up to the table, accompanied by Dr. Silverstein.

No, no, you stay right there, Mr. Stever.

All right, what I'd like to do is go ahead and have your statement, Dr. David, and then we will just get into a good little round table discussion of the issues with all of you, and then later on bring up General Welch as well.

STATEMENT OF DR. EDWARD E. DAVID, JR., CHAIRMAN, PANEL ON POST-CHALLENGER ASSESSMENT OF THE SPACE SHUTTLE FLIGHT RATES AND UTILIZATION, NATIONAL RESEARCH COUNCIL, WASHINGTON, DC, ACCOMPANIED BY DR. ABE SILVERSTEIN, CONSULTANT

Mr. **David**. Mr. Chairman, I will try to give an abbreviated version of this, but would request that the entire testimony be put in the record.

Mr. **Nelson**. Sure. And you can expect some more interruptions because, as you know, we are on the Trade Bill, and there's one amendment right after another, and we'll be fortunate if, in fact, they don't have some recorded votes, but I expect some recorded votes.

Go ahead, Dr. David.

Mr. **David**. Mr. Chairman, I am delighted to be here to represent our committee and its findings. Basically we were tasked to look at the question of shuttle flight rates, to assess the assumptions made by NASA in partitioning payloads between the shuttle and ELVs, and to estimate the cost tradeoffs of a mixed fleet.

What I will do is concentrate on item one, because I understand it's of particular interest to the committee.

Basically our findings are that three Orbiters can sustain a flight rate of eight to 10 per year, and it is possible that those three Orbiters could be—could handle 12 per year for a very limited time, a surge rate of 12, and by a short time we mean three or four—three to four months.

For four Orbiters, the rate is 11 to 13 per year, with a surge rate of 15.

Now these rates could be reduced considerably by contingencies which put an Orbiter out of action for an extended period of time.

And furthermore, extended use of the shuttle, say 15 or 20 years into the future, suggests the possible need for replacement Orbiters at certain appropriate intervals of time, and we are thinking here of treating the Orbiter fleet more or less as you would treat any transportation fleet. There has to be replacements at certain intervals of time.

We assumed in our study that the nation would continue to have a manned space flight program, and that flying manned vehicles would be a part of that on a more or less regular schedule.

We tried to estimate the flight rates for both the three-Orbiter fleet and a four-Orbiter fleet without making any assessment as to which size fleet was most desirable.

It is worth nothing here that during a shuttle launch and during the passage of the vehicle through the atmosphere, the shuttle is stressed far nearer its design limits on every flight than is the case with ordinary aircraft, for which such an occurrence is a rarity.

So for the shuttle, the need for adequate safety reviews, logistics support, spare parts, extensive inspection and maintenance, and extreme care in every facet of the turn-around operation, cannot be overemphasized.

So the panel arrived again at an estimate slightly below to slightly above three launches per year per Orbiter. We based this on a five-day, three shift per day work week, an average mission duration of seven days in space, six days for ferrying the Orbiter to the Kennedy Space Center, with allowances for weather uncertainties (we assumed that the Orbiter would land at Edwards Air Force Base for the foreseeable future), and periods of major maintenance every few flights, depending upon the inspection of the fundamental structure of the Orbiter and certain other elements of the Orbiter.

We think that a five-day work week assumption, as opposed to a seven-day work week assumption, is prudent because it would allow the same ground crews on each shift to take turn-around operations, rather than necessitating crew changes over a seven-day period or, alternatively, requiring the same crew to work seven days a week.

The conservative estimate of launch rates is based on a turn-around time of 75 working days per month, which represents—I'm sorry, conservative estimate is based upon a turn-around time of 75 working days for the turn-around, assuming 21 work days per month to get the launch scheduled.

That represents the average duration experienced to date with turn-around, the 75 days. The optimistic estimate is based on a 20 percent reduction to a 60-day turn-around time, and we expect that to be realizable with further experiences—experience.

And for that reason, if you do the arithmetic, it comes out the three-Orbiter fleet can give us up to 10 launches a year, and a four-Orbiter fleet, 11 to 13 per year.

And we have assumed, as I think I have already said, in those estimates that no Orbiter is lost or rendered inoperable, and sufficient logistic support is available to meet the manifest with reasonable confidence, and that structural and other systems problems requiring recurring downtime for extended periods do not occur.

Now the most critical assumption in estimating flight rates is that no Orbiter will be lost or become inoperable during—for any significant period of time, and you can't rule out the possibility of that happening and, therefore, our estimate of rates should be taken as an upper bound on what can be achieved.

And as I just said earlier, we viewed the shuttle in terms of a fleet, in the same manner that we viewed other transportation systems, and so consideration has to be given over the lifetime of that fleet to maintenance of the fleet and to replacements as dictated by experience.

Now with respect to payload partitioning, the backlog, we think, of manifested payloads that we see today is likely to decline as a result of delays and foregone windows of opportunity, and the heaviest launch demand that we see in the future is for the space station, and we conclude that a resolute NASA effort to procure ELVs is likely to be required to fulfill the space science program and commercial contracts that NASA has on its books.

We had to note that NASA, even though the Air Force is now procuring a large number of ELVs for its own purposes, that NASA has not yet implemented or begun to implement a plan to procure any ELVs, and if production were to start immediately, the availability of an ELV or ELV fleet as a shuttle alternative, is likely to be severely limited until the early 1990s, except for the DOD payloads, for which planning is moving forward on ELVs. And hence, I think you have to conclude that NASA is putting sole reliance on the shuttle for many years to come.

I won't talk further about the manifest. I think I have given you the conclusions, and I think that it is worth noting, however, one additional fact. Of the 130 odd payloads that NASA has on its books for launch at the present time, and I'm—this is as of October 1986, so the numbers probably changed to some degree—they are mostly space science payloads. NASA estimated to us that approximately 22 of those 130 could be offloaded to ELVs.

However, there is no resolute ELV procurement effort by NASA at the present time, and it seems to us that that would be required to fulfill the commercial contracts which NASA intends to honor and the space science program.

Now with regard to cost tradeoffs, I think I can make that very brief. It appears to us, according to an analysis that was made available to us by the Aerospace Corporation, that the total cost to the nation is relatively independent of how shuttles and ELVs are mixed, and the arithmetic for that is given in our report, and I won't go into it in detail, but I do think it is significant to say that the size of the space program will determine—will be the primary determinant of cost, and not a question of whether ELVs or shuttles are mixed in any particular proportions.

Mr. Chairman, that concludes my testimony.

[The prepared statement of Mr. David follows:]

TESTIMONY BEFORE THE
U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

by

DR. EDWARD E. DAVID, JR.
CHAIRMAN, PANEL ON POST-CHALLENGER ASSESSMENT OF SPACE SHUTTLE
FLIGHT RATES AND UTILIZATION
NATIONAL RESEARCH COUNCIL

April 30, 1987

Mr. Chairman and Members of the Subcommittee:

On behalf of the National Research Council's panel on A Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization, I am pleased to appear before you today to present the results of our study.

The task put to our panel was basically to:

1) assess the possible space shuttle flight rates using as a baseline the most recent flight manifest,

2) assess the assumptions made by NASA in the partitioning of payloads between the shuttle and ELVs, and whether these assumptions are reasonable, and

3) estimate cost trade-offs of a mixed fleet.

I propose to concentrate on item (1) as I understand it is of particular interest to this Subcommittee, and then touch briefly on the other items.

ITEM #1 Our findings regarding flight rates are the following:

- Three Orbiters can sustain a flight rate of 8 to 10 per year, with a surge rate of 12 per year for a limited time--3 to 4 months.

- For four Orbiters the rate is 11 to 13 per year with a surge to 15.

- These rates could be severely reduced by contingencies which would put one or more Orbiters out of operation for an extended period of time.

- Extended use of the shuttle—15-20 years—suggests possible need for replacement Orbiters at certain intervals of time.

At the outset of the study the panel had to make an assumption regarding whether the national intent was to have a sustained manned space flight program—one in which flight was a regular and continuing occurrence year in and year out—or to treat the shuttle fleet as a declining resource (like the Apollo) which, in due course, would, through use or accident, diminish to zero. It also had to decide whether the requested assessments should apply to the transition period between now and 1991 or to the period thereafter when both the shuttle and an ELV fleet presumably would be available for launch.

Considering the nature of the requested assessments, the panel decided to assume a sustained manned flight program and to consider flight rates in both the post-1991 time frame and the buildup before 1991.

It was the understanding of the panel that the purpose of the assessments was to estimate flight rates for a 3- or 4-Orbiter fleet. Both fleet sizes were therefore addressed without making any recommendation on which fleet size is preferable or needed.

During its short passage through the sensible atmosphere, the shuttle is stressed far nearer its design limits on every flight than is the case for transport aircraft and military aircraft except in wartime, for which such an occurrence is a rarity. So, for the shuttle the need for adequate safety reviews, logistics support, spare parts, extensive inspection and maintenance, and extreme care in every facet of the turnaround operation cannot be overemphasized.

The panel arrived at estimates of slightly below to slightly above 3 launches per year per Orbiter. Both conservative and optimistic estimates are provided based on a 5-day/3 shift per day/work week, an average mission duration of 7 days, 6 days for ferrying the Orbiter to the Kennedy Space Center with allowance for weather uncertainties (we assumed it would land at Edwards AFB for the foreseeable future), and periods of major maintenance every few flights depending upon inspection of the fundamental structure and other elements of the Orbiter.

The 5-day work week as opposed to a 7-day work week was considered prudent as it would allow the same ground crews on each shift to undertake turnaround operations rather than necessitate crew changes over a 7 day period or, alternately, require crews to work 7 days a week for extensive periods of time.

The conservative estimate is based on a turnaround time of 75 working days (21 work days/month) which represents the average duration experienced with the shuttle to date. The optimistic estimate is based on a 20% reduction to a 60-day turnaround time expected to be realizable with further experience.

Thus, the average yearly sustainable flight rate for a 3-Orbiter fleet is 8 to 10. For a 4-Orbiter fleet the sustainable rate becomes 11 to 13. It is expected that these rates could be achieved following a transition phase of approximately 2 years after resumption of shuttle operations and, importantly, providing:

- no Orbiter is lost or rendered inoperable,
- sufficient logistic support is available to meet the scheduled manifest with reasonable confidence, and
- structural or other system problems requiring substantial, recurring downtime do not occur.

Under special conditions, the 3-Orbiter flight rate might surge to approximately 12 per year and the 4-Orbiter one to 15 per year for short periods of time—3 to 4 months—and with stringent operational limitations such as reasonably standard payloads and relatively short mission durations.

It should be noted that flight rates of 12 per year can be achieved only with augmentation of ground resources. Manpower at Johnson Space Center and spare parts production would have to be increased. Also, additional crew training facilities including software need to be procured for flight rates up to 12 per year. However, present ground facilities at KSC with planned augmentation—e.g., the Orbiter Maintenance Facility—appear adequate to handle such flight rates.

The most critical assumption in estimating flight rates is that no Orbiter will be lost or become inoperable for a significant time. The possibility of a loss or irreparable damage to an Orbiter cannot be discounted. Furthermore, if the present shuttle is to meet manned launch requirements in the long term—say, for the next fifteen or twenty years—account must also be taken of normal wear and the need to retire Orbiters as well as the possibility of other contingencies arising.

As such, the shuttle can be viewed in terms of a fleet in the same manner as other transportation systems and consideration should be given to having reserve vehicles in suitable stages to provide the necessary measure of operational continuity, and to replace vehicles at appropriate intervals of time. This would necessitate a suitable balance between production rates and replacement requirements.

An important point is that, with a 3- or 4-Orbiter fleet it is quite possible that, on average, fewer than 3 or 4 Orbiters will be in operational status over time. Consequently the flight rates of 8-10, and 11-13 for 3- and 4-Orbiter fleets respectively must be viewed as upper limits of the panel's estimates.

ITEM #2 The findings with respect to payload partitioning are as follows:

- The backlog of manifested payloads is expected to decrease as a result of delays and foregone windows of opportunity.
- The heaviest launch demand arises for the Space Station.
- A resolute NASA effort to procure ELVs is likely to be required to fulfill its space science program and commercial contracts.

The panel was asked to examine the assumptions made by NASA in the partitioning of payloads between the shuttle and expendable launch vehicles. This raises the issue of the availability of expendable launch vehicles. While the Air Force is procuring a number of Titan IV heavy launch vehicles and medium launch vehicles based on the Delta rocket (MLV) their early production seems likely to be devoted to Department of Defense payloads. We understand that NASA has yet to implement a plan to procure ELVs. Even if production of ELVs were to start immediately, their availability as a shuttle alternative for other than DoD payloads is likely to be severely limited until at least the early 1990s. Hence, NASA is putting sole reliance on the shuttle for years to come.

With the temporary cessation of shuttle flights, it is expected that the backlog of manifested payloads will actually decrease as some previously scheduled satellites will not be flown and the DoD will off-load many payloads for launch on ELVs. However, with the launch rates estimated here, launch demand is likely to exceed supply for the foreseeable future.

The heaviest launch demand arises for the Space Station. Although the number of shuttle launches anticipated for the 3-year construction phase of the Space Station has been reduced considerably from the original 32, they still would take up most of the capacity of a 3-Orbiter fleet. Regarding the Strategic Defense Initiative, the SDI Office estimates the need for only 1 to 2 flights per year during the experimental phase and foresees the possible development of a heavy lift launch vehicle for eventual follow-on phases.

Many military payloads are slated for launch on the Titan IV and the MLV. NASA has not scheduled an ELV launch capability to accommodate the large number of space science or the commercially contracted payloads that could be off-loaded from the shuttle. Some commercial payload companies are now considering launch on foreign launch vehicles or on vehicles being proposed by U.S. industry. But these possibilities are still many years off.

Of 130-odd payloads of its own--mostly space science payloads--NASA estimated that approximately 22 could be off-loaded to ELVs. However, a resolute ELV procurement effort by NASA, or other civil government agency, is not yet in place but seems to be required to fulfill in a timely way commercial contracts and NASA's space science program.

ITEM #3 With regard to cost trade-offs of a mixed fleet the finding is:

- The total cost to the nation is relatively independent of the shuttle/ELV mix.

Due to the many political, financial, and market variables in the immediate post-Challenger environment, it is not possible to make detailed cost trade-off analyses at this time. Very limited cost data was available at the time this study was under way. From calculations provided us by the Aerospace Corporation it appears that total national space launch costs depend principally upon the size of the nation's space program and to a much lesser extent on the mix between shuttle and ELV launches. That is to say that the total cost to the nation to put a given total weight into orbit over time is relatively independent of the shuttle/ELV mix. It is felt that policy decisions such as the long-term commitment to man's presence in space, the timing and cost of a Space Station, the nature of the SDI, and the robustness of national security space systems will have a greater effect on national launch costs than the shuttle/ELV mix.

In summary,

1) Regarding flight rates,

- Three Orbiters can sustain a flight rate of 8 to 10 per year, with a surge rate of 12 per year for a limited time--3 to 4 months.
- For four Orbiters the rate is 11 to 13 per year with surge to 15.
- These rates could be severely reduced by contingencies which would put one or more Orbiters out of operation for an extended period of time.
- Extended use of the shuttle--15-20 years--suggests possible need for replacement Orbiters at certain intervals of time.

2) Regarding payload partitioning,

- The backlog of manifested payloads is expected to decrease as a result of delays and foregone windows of opportunity.
- The heaviest launch demand arises for the Space Station.
- A resolute NASA effort to procure ELVs is likely to be required to fulfill its space science program and commercial contracts.

3) Regarding cost trade-offs,

- The total cost to the nation is approximately independent of the shuttle/ELV mix.

Mr. Chairman, this concludes my testimony and I will be happy to answer questions.

DR. EDWARD E. DAVID, JR.
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EDWARD E. DAVID, JR. has been a pioneer in the field of electronic communication and computing, as well as energy systems. His career exemplifies leadership in scientific and engineering policy-making which has helped shape the direction of research in the U.S. today. Dr. David is currently President of EED Inc., consultants to industry and government on technology and research management. His previous positions include Science Advisor to the President of the U.S.; Executive Director, Bell Telephone Laboratories; President, Exxon Research and Engineering Company, and Executive Vice President, Gould, Inc.

He is the recipient of twelve honorary degrees including the Polytechnic University, 1971; Rensselaer Polytechnic Institute, 1982; Rutgers University, 1984; New Jersey Institute of Technology, 1985; University of Pennsylvania, 1985.

Dr. David has received several awards, among them: Society of Research Administrators for Distinguished Contribution to Research Administration, 1980; New Jersey Science/Technology Medal, 1982; Industrial Research Institute Medal, 1983; Scientist of the Year, Research & Development magazine, September, 1984; Arthur M. Bueche Award, National Academy of Engineering, October, 1984, Delmer S. Fahrney Medal, The Franklin Institute, April, 1985.

His current professional and business associations include; White House Science Council; U.S. Representative to the NATO Science Committee; New Jersey Governor's Commission on Science and Technology; New York Mayor's Commission for Science and Technology; Life Member, Massachusetts Institute of Technology Corporation Board; Trustee, Carnegie Institution of Washington; Courant Institute of Mathematical Sciences (New York University); Member, National Academy of Sciences; National Academy of Engineering; American Academy of Arts and Sciences; American Philosophical Society; National Academy of Public Administration; Fellow, I.E.E.E., Acoustical Society of America, and American Society for Engineering Education (honorary).

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Mr. **Nelson**. Now, as I understand it, you have a time constraint about 11:30; is that correct?

Mr. **David**. That's right, Mr. Chairman.

Mr. **Nelson**. And Dr. Stever, yours is about 11:45?

Mr. **Stever**. Yes.

Mr. **Nelson**. Okay. Now, General, do you have a time constraint?

General **Welch**. I don't think so.

Mr. **Nelson**. All right. Well, your testimony relates directly to Dr. David's, and I would like to get some interchange going there with yours. Let me just stop the proceedings here in the interest of time for the members. Let's direct any questions to Dr. Stever and Dr. David, and see how that goes in the consumption of our time, and then how it flows. We'll get you up, General, and I'd like to get some interchange going with you and Dr. David.

All right. Let's see. Mr. Skaggs.

Mr. **Skaggs**. Thank you, Mr. Chairman.

Just on your last point, Dr. David, in your estimation that the question of a mixed fleet doesn't really carry implications as to cost, does that include conceivably looking at a demand for launch that would require, if it were to continue along its present course, at least a fifth Orbiter capability in order to provide that kind of fleet management approach that you suggest, or just looking at the three or four that you mentioned earlier in your testimony?

Mr. **David**. The calculation was done on the basis of three or four Orbiter fleet, but I believe that because of the calculation, we can conclude that if you look over an extended period of time and not look at cash flow in any particular year, that the conclusion is valid on a broad base.

Mr. **Skaggs**. Does it also consider opportunity costs as far as the loss of launch windows for some of the payloads that are going to be backed up if we wait for shuttle capability?

Mr. **David**. No, it does not include that, and I think it's a very good point that you make.

Mr. **Skaggs**. Is there any effort being made to estimate and factor those in?

Mr. **David**. We did not try to factor those costs in because they are very difficult costs to tabulate and to get reasonable estimates on.

However, we were told by many of the commercial contractors who were waiting for launch, and by our space science colleagues, that it is much more important to have a timely launch—in other words, have the availability of a launch window, which is assured—than it is to worry about the last few dollars of launch cost, per se.

In other words, that at least in the commercial area, the cost of launch—I suspect this is true also for the space science payloads—the cost of launch itself is a small part of the total cost of the mission and, therefore, it is not a very large factor.

Mr. **Skaggs**. Well, given that, and given your statement that opportunity costs were not factored in, would that then suggest the conclusion that we should find a greater bias toward ELVs of cost-effective—that it's really not a cost-neutral situation?

Mr. DAVID. Let me give my own opinion on that, because I don't think the committee, my panel, addressed that issue completely or specifically.

I would certainly agree with what you have just said. Maybe Dr. Silverstein would have something he would like to add to that. Abe, would you feel—how would you feel about that?

Mr. SILVERSTEIN. Well, my personal feeling would be that the ELV approach would be cheaper, taking these things into account.

Mr. SKAGGS. One question perhaps going back to Dr. Stever. Our colleague, Mr. Torricelli, isn't here this morning, but has been very interested in the issue of second sourcing for the SRB. I don't know whether your group has been charged with looking into that particular aspect or not. Whether it has or not, do you have any view you would like to share with us on that?

Mr. STEVER. Yes, we have made recommendations on alternative designs ranging all the way from what I would say short term alternatives with respect to the way the insulation is bonded and the detailed design of the current joints, ranging from there to long term alternatives. We believe in the long run there should be a major redesign program to take care of the most modern technology and ideas and so on. But that's a fairly advanced one, and certainly can't be considered in this short time scale that we have to get the NASA—the shuttle relaunched. Somewhere in between there are some alternatives that are large. We couldn't do it in the short scale, but we wouldn't—couldn't—they would come ahead of this other. But the alternative—the alternative second source did not appear to be too attractive to our group, although we haven't talked a great deal about that, simply because we should—we feel that we should put all the effort that we can on this one to make it proper for this time period. We would rather have any extra budget money and so on go into a longer term. But there are some very good ideas stretched all the way from short term alternatives to very long term alternatives, and if we had all the money in the world, we would do a little more.

Mr. SKAGGS. Thank you, Mr. Chairman.

Mr. NELSON. Mr. Packard?

Mr. PACKARD. Thank you, Mr. Chairman.

The—with the backlog that presently exists, Dr. David, and the obvious delays that we are going—and much slower rate of flight that we are going to have to experience for the next three or four years, is it obvious to you that we will not be able to supply the need for launching without ELVs?

Mr. DAVID. The panel—my panel definitely drew that conclusion.

Mr. PACKARD. Can we meet the need with a mixed fleet?

Mr. DAVID. Probably not.

Mr. PACKARD. And if that is the case, then the demand continues to be greater than the ability to launch or the backlog continues to increase over the years, where will we pick up that additional need?

Mr. DAVID. I think that launches of payloads will be pushed off into the future for a long period of time, and I would not expect to see us catch up with demand until well into the 1990s at the earliest.

Mr. **Packard**. What would be your opinion or the opinion of your committee on private sector competition?

Mr. **David**. I think that the principal private sector launch capability—and I'm speaking for myself here now—would come from the contractors to DOD, and perhaps one additional contractor who has in the past built launch vehicles for DOD and NASA.

In other words, there would be three principal competitors. I believe that at least for the next four or five years, the possibility of securing a large number of ELVs from those contractors is small, because they will be operating for the DOD, they are already under contract, two of them, to DOD, and that the availability of ELVs is going to be very short for the foreseeable future. That is, up until about 1990 or 1991.

Mr. **Packard**. Would you recommend that the government make launch facilities available to the private sector if, in fact, the private sector does choose to get into ELV launches in—and leave the government launches to government vehicles, recognizing that there will probably be a great deal of private sector launch need that would not be met or be significantly delayed?

Mr. **David**. I'm not sure I understand the question.

Mr. **Packard**. Well, I was wondering if you would recommend or have given thought to the leasing or the charging of a fee for the use of launch equipment or launch facilities for private contractors or private launching of vehicles.

Mr. **David**. Our committee didn't examine that, per se, but in talking to the contractors who would be involved, I believe that they are counting on being able to use NASA facilities for a fee to launch commercial satellites. I think there is always a question of interference between those launches and federal or government launches. But I think in most cases this can be worked out, so I believe——

Mr. **Packard**. The launch facilities could be used a great deal more than what we will have available vehicles to launch?

Mr. **David**. I believe so. I believe that's correct.

Mr. **Packard**. Dr. Stever, you mentioned in your testimony the new design for the O-rings calls for a heater to allow for launching in all kinds of weather. Is that the understanding I had?

Mr. **Stever**. Well, not all kinds of weather, but in—at lower temperatures than the O-rings could stand without the heaters.

Mr. **Packard**. Were there other parts of the shuttle package that was affected by the low temperatures other than the O-ring joint?

Mr. **Stever**. I don't believe that there were others that were significantly affected. The O-ring joint was the very obvious one.

Mr. **Packard**. So the committee's feeling was that if we could solve the low temperature problems that were created at the O-ring joint, if those could be corrected, that it would still be safe to launch under conditions similar to what the *Challenger* launched?

Mr. **Stever**. I think so. There are O-rings in the case-to-nozzle joint, but that has some—there is a gas flow there that keeps it warmer than the case itself, so the case is the most vulnerable.

Mr. Packard, I would volunteer information that an effort was started and that we recommended strongly in favor of that to find O-ring materials that had a wider response rate, that is could cover the open gap when the pressurization of the case took place, and to do it rapidly enough so that gas did not escape through those O-rings, and that research program came up with some materials that have those capabilities, but they didn't work very well with the greases that are needed, the grease that is needed to prevent rust and deterioration, which is very important, too, because you can have stress corrosion, which is bad. And so NASA selected the heater ring in order not to wait until some—something was found that did work. The search, I believe, is still going on, but it is not a high pressure priority.

Mr. **Packard**. I was out to Utah to review a few months ago their new designs of the O-ring joint. I don't recall a heater being discussed at that point, but perhaps maybe that's been added since. But even at—has the committee reviewed the redesign to see if without a heater or a heating activity at the joint, the new design would adequately resolve the problems that we experienced in the *Challenger*?

Mr. **Stever**. I don't think—well, first of all, there are several parts of the joint that are improved. It's not just the O-ring. The gap opening in the metal parts, the capture feature in the metal parts in the joint, have improved the performance or will improve the performance, all the preliminary tests indicate that, and we see no reason why that won't be true. So the O-ring will have less of a task.

Nevertheless, I don't think anyone is going to want to operate the current O-rings at the low temperatures. In fact, even above the 20 to 30 degrees that was talked about in the 51-L accident. So temperature is still a very important consideration.

Mr. **Packard**. Is the design as you've reviewed it with the heater such that there are electronic and computerized monitoring devices to determine whether they are functioning right or——

Mr. **Stever**. Well, the main thing you would want is temperature measurement close to the thing, instead of just ambient temperature measurement, and I believe that program has a lot more temperature measurement conditions in it.

Mr. **Packard**. Thank you, Mr. Chairman, very much. I appreciate very much your testimony and the work that all of you have done on that.

Mr. **Stever**. Thank you.

Mr. **Nelson**. Thank you, Mr. Packard.

Mr. Volkmer.

Mr. **Volkmer**. Thank you, Mr. Chairman.

I'd like to just briefly continue on this discussion on the SRBs. We are still discounting the use of a solid rocket, complete rocket, just rather than building one in parts.

Mr. **Stever**. The monolithic—you are referring to the monolithic——

Mr. **Volkmer**. Right.

Mr. **Stever**. No, we haven't in the long run, but first of all, the—that proposed monolithic rocket propellant, that's what is monolithic about it, it is still a jointed case—that still needs a joint near the nozzle. So you have got to solve that joint problem, period.

The joints in the other parts of the case are easier to solve, obviously, with the single propellant grain, but we estimated that by—that that would take considerably more time, even though it may be better in the end to do it, considerably more time than the current redesign effort should take. So the decision really is—has a time factor decision in it there.

Personally I would like to see some day the monopropellant.

Mr. VOLKMER. Well, I believe it would be a lot safer. Now maybe I'm wrong; I'm not an engineer.

Mr. STEVER. The—you know, we may come up with a new design that is a very safe design as it is. There's a good probability that will happen, and so if that does happen, and we can use that for a number of years and then have a more reasonable design development program in the future, I think it would be very good.

Mr. VOLKMER. Of course, the monolithic would have to be poured and everything right down at the Cape?

Mr. STEVER. Yes. Well, that's certainly—seems like the most economic—economical proposal. But the—to bring on a whole new pouring technique—technology, it's been done before, but it hasn't been done with all of the safety precautions in the development of all the techniques and the assurances that monopropellant is truly a perfect grain as opposed to having defects in it. I think there will be quite a bit of technology development before that—it could really come on line.

Mr. VOLKMER. All right. Then as I asked one of the panel yesterday, what concerns me even with the new design on the SRBs, is that we appear to be committed to a policy of reusability, and refurbishing, and then repouring, and we know we have problems of shipping those casings from Utah down, that they don't—they come out of round. They are damaged when they hit the ocean, there is some corrosion. Is it going to be harder to fit these with the new design when they come in to Kennedy or not? Or do you know?

Mr. STEVER. Well, first of all, the technology of fitting the two cases together has been improved. Our panel has very definitely been concerned about the very tight metal-to-metal fit that's required with this new capture feature, and particularly we have been worried about corrosion, stress corrosion that may develop after those cases go into the salt water environment before they are picked up.

We think that the NASA team is looking very carefully at these problems. There's been some encouraging experimentation, but I have to caution you that we won't really know how reusable they are, how many times, until we begin to get the experience. And that, I think, will remain an "if" for a while.

The important thing, as far as we are concerned, is to make sure that when they are reused or when they are used the first time when they are reused is that the inspection and the care of them in the assembly and so on is very good so we know that they are in good shape when they are used. But we can't tell about that——

Mr. VOLKMER. So, in other words, we may have to increase our inspection and our——

Mr. STEVER. I think the care with which we do that and the amount, yes, I would believe it is necessary.

Mr. VOLKMER. Well, what I am hearing, Dr. Stever and Dr. David, is that basically—and what I've heard yesterday is that we are going to do less than what we proposed to do, I can remember four and five years ago when at this time right now we were going to be flying about 18, and by '88 we were going to be doing 24 a year with our four-Orbiter fleet. We know now, from hindsight, that that's not possible, it's not going to happen, even if we still had Orbiters, we wouldn't be able to do it with everything considered.

And I also find, though, that per-flight cost is going to go up from what was anticipated back then. Do you agree with that?

Mr. DAVID. As I think I have indicated before, we didn't look at the per-flight cost, but you do look at reasonable depreciation rates on the Orbiters and the SRBs, and if you look at the out-of-pocket expenses, the costs are going to go up very considerably, and there is a fixed cost down at the Cape.

Mr. VOLKMER. Right. With all the necessary——

Mr. DAVID. Which is going to be spread over a fewer number of flights, so the—that cost is going to be higher. The answer is the costs are going to go up considerably. We are going to be operating at about half the level that was anticipated before the accident, and that would say that the costs are spread over half the number of flights.

Mr. VOLKMER. All right. And I quite agree with you, I think we better get on with the idea that—get into the ELVs and be prepared to use them, because if I remember right, the demand was that we'd be close to 20 to 24 a year in the 1988 and 1990 timeframe, and that was before the space station. And then you put the demands of the space station on top of it, the demand is going to be a lot greater than what we were prepared to handle right now.

Mr. DAVID. I think that's correct, and it is fortunate that we do have a rather good group of contractors who can produce the ELVs, at least in a reasonable timeframe, as they are needed, to handle the demand. And I think we ought to get on with it.

Mr. VOLKMER. When you determined, Dr. David, that four orbiters, 11 to 13, and three orbiters, 8 to 10, in that determination, were you anticipating that one orbiter would be out of service at least every year almost during a period of time to refurbish, to make repairs, et cetera?

Mr. DAVID. Yes. We assumed that routine maintenance was going to absorb a substantial period of time and that's how we came to the numbers that we projected.

Mr. VOLKMER. Now, what do we need to do about spare parts?

Mr. DAVID. Well, we have looked, not as carefully as we might at the spare parts problem, but we do think that an augmentation of the spare parts inventory at the Cape is necessary. We also think that turn around time between the Cape, the contractor who does the repair on the part and the return of the part to the Cape needs to be reduced. That is going to take some doing because at the moment, I understand that length of time is increasing, not decreasing.

We definitely need to augment the logistics activities of the operation.

Mr. VOLKMER. Let me ask you this; if we would continue to cannibalize the orbiters as we were doing before the Shuttle disaster including on the *Challenger*, if we do that, will that also reduce further what you are saying here on the number of flights, or did you anticipate that cannibalization to the point where—I don't remember, 100 or so parts on the *Challenger*.

Mr. DAVID. Mr. Volkmer, we assumed that the proper kind of logistics system would be put into being at the Cape. If it is not, then these numbers are high.

Mr. VOLKMER. In other words, we are going to have to do better on anticipation of spare parts and better logistics in getting them replaced and being prepared to put them—instead of take them off one orbiter and put them on another, put them on the orbiter that needs to be repaired?

Mr. DAVID. That's correct.

Mr. VOLKMER. Thank you, Mr. Chairman.

Mr. NELSON. Mr. Smith?

Mr. SMITH of New Hampshire. I know we have a vote, Mr. Chairman. I just have a couple of quick questions on the Shuttle utilization. I came in late. If it was asked, I apologize.

In your statement, Dr. David, you and many others seem to conclude as you say exactly, a resolute NASA effort to procure ELVs is likely to be required to fulfill the space science program and commercial contracts, yet it is not being done. In fact, you go on to say that some commercial payload companies are now considering launch on foreign vehicles.

Would you like to offer any reason as to why NASA is not moving at a greater pace toward ELVs?

Mr. DAVID. I think there are a number of reasons and I can guess at some of them but I wouldn't want to try to support them with documentation. I think there is a certain cultural aspect at NASA. They have been focusing on the Shuttle as the principle vehicle for so long that it is very difficult for them to change around and do something that is entirely different. That's number one.

Number two, it seems to me that the ELVs—an ELV of a proper size and length is going to be a costly undertaking. There is a budget question. I think that has been one of the aspects which has prevented NASA from proposing to the Congress a substantial ELV program.

In other words, the money is difficult to find and it may not be available. That's the second principal thing.

The third is that NASA has felt for a long time that the Shuttle provides an opening to the future, if you will, an open ended capability which can be used for a wide variety of activities and that they should continue to emphasize the use of the Shuttle as their primary vehicle.

Mr. PACKARD. Will the gentleman yield for a clarification or a point on that issue?

Mr. SMITH of New Hampshire. Yes.

Mr. PACKARD. If NASA for budget reasons was required to choose between a mixed fleet of ELVs and three orbiters or a fourth orbiter with no ELVs because of budget constraints, what would your recommendation be?

Mr. DAVID. I was afraid that question would come up, Mr. Packard. Our committee was not pointed at trying to answer that question. We weren't asked that question. We didn't answer it. I can give you my own opinion, and it's quite unequivocal. A mixed fleet of ELVs and Shuttles is much preferable to a fourth orbiter.

Mr. Packard. Thank you.

Mr. Smith of New Hampshire. Along that same line, and I know we have to vote, Mr. Chairman, just one final question, would you advocate restricting the Shuttle to strictly manned flights and manned related research and ELVs? Dr. Silverstein, you said ELVs are cheaper. Does that make sense? Try to get the commercial sector, as Mr. Packard said, involved here and do these things strictly through ELVs and keep the Shuttle just for manned flights?

Mr. David. I would favor that direction, Mr. Smith, but there is a factor which pushes it in the other direction, and that's the reliability of the launch. We know that ELVs fail more often than Shuttles do. We know that manned qualification of the Shuttle requires that it be much more reliable. As the cost of payloads goes up, whether they require man or not, manned or not, the launch costs are going to be a small part of the total cost of the system, as I already said, and there is going to be a desire for increased reliability.

There is nothing to say that ELVs, if they are redesigned and designed carefully, can't reach the level of reliability that the Shuttle has.

Mr. Smith of New Hampshire. There is some argument in terms of the conversion costs to some of these payloads going on to ELVs; right?

Mr. David. That's correct. That is also true. That is a short term consideration, because most of these payloads can be designed to go on either. It is just a question of getting that done. There is a real question of reliability here which pushes it in the other direction.

Mr. Skaggs. Will the gentleman yield?

Mr. Smith of New Hampshire. I'd be happy to yield.

Mr. Skaggs. Thank you. Just a real quick question on that point. In your testimony, you said that NASA had estimated that 22 of the 130 backlogged payloads could be moved to ELVs. Do you agree or question that number?

Mr. David. We saw no reason to question the number. We looked at the payloads and it seemed to be a reasonable partitioning, Mr. Skaggs.

Mr. Skaggs. Thank you.

Mr. Nelson. The Committee will stand in recess. We will get back and still make your time.

Mr. David. Thank you, sir.

[Brief recess.]

Mr. Nelson. Dr. David, to accommodate your schedule, let's get you on the way here.

Mr. David. Thank you, Mr. Nelson.

Mr. Nelson. Your estimates of flight rates and those of NASA's are considerably different. How can you account for that?

Mr. David. Mr. Chairman, I can't account for it in a detailed way. We, of course, worked rather closely with NASA in arriving at these numbers. We did not get any strong objections from NASA to these estimates. This would say to me that NASA is setting itself ambitious goals and would hope to achieve them, but if they don't, they will come back to the numbers more like the ones we have.

Mr. **Nelson**. I think we tend to agree more with yours. Of course, it worries us from a standpoint that all of your budgetary planning, all your manifest planning, how many ELVs you are going to have to have, all of that directly keys off of what is going to be the flight rate.

Mr. **David**. That's correct. I think it would be much more prudent for NASA to work at the lower numbers, because as I tried to say earlier, the critical feature of launch performance in the view of many people we talked to is the reliability, number one, and the schedule, maintenance of a reliable schedule, number two. Maybe reverse even, the reliability of the schedule is very important for commercial and scientific payloads. That is a prime consideration.

Mr. **Nelson**. I will wait and save it to get in with General Welch, on more detailed questions on the ELVs and so forth. You have pointed out in your testimony that thus far, NASA has not come forth asking for any ELVs. It is rather extraordinary in the fact that it is a year and a half after the accident. It's apparent to all that there is going to have to be a mixed fleet.

I think that the sentiment is here in this Committee that we are going to provide for some ELVs for the 1988 budget. Any comment on that?

Mr. **David**. Well, Mr. Chairman, I'd like very much to see that. I believe it would please practically everyone in the user community. I might just add, however, one caveat. In our report, we say that you have to look at the Shuttle as a fleet which must be maintained and sustained over a period of years. Unless there is a good program of spare parts, Shuttle building, which is scheduled on a reasonable and appropriate basis, the Shuttle fleet will be a declining asset and will eventually become unavailable to us. I think that is as important as seeing that we have the right mix of Shuttles and ELVs.

In light of my answer to Mr. Packard, that I would prefer at the present time to see an ELV program to a fourth orbiter, I would just add that caveat. I think you have to have both if you intend to use both. If you allow a transportation fleet to decline without a building program to replace the elements of it, you will not have it for very long. We need both, Mr. Chairman.

Mr. **Nelson**. Thank you very much. We have met your time constraints. Thank you for being with us today. We appreciate it very much.

Mr. **David**. Thank you for the opportunity.

Mr. **Nelson**. Dr. Stever, tell me about those heaters. Are these sort of strap on heaters around the joints?

Mr. **Stever**. Yes.

Mr. **Nelson**. Do they stay on or do they come off prior to launch?

Mr. **Stever**. They don't want them on the test stand for possible damage. They can't drop there. I think this is still an open issue. The possibility of dropping them off right at launch is one, but then you have debris on the test stand and the chance of serious damage.

Mr. **Nelson**. They are planning that they stay on?

Mr. **Stever**. Yes.

Mr. **Nelson**. We had talked about a number of questions that basically I would like to get for the record. Your comments about the advanced solid rocket motor.

Mr. **Stever**. The advanced solid rocket motor is our version, I guess, of one part that Dr. David just mentioned, that if we have a manned fleet, a Shuttle fleet, we think it would be very important to continue the improvement, updating, new technology of that, and certainly an advanced solid rocket motor would do that. We could use new technology, new ideas, and we could try out some of the ideas that people have proposed as shorter term alternatives as well, many of which are very good.

Can I expand on that a little?

Mr. **Nelson**. Please.

Mr. **Stever**. Our panel has pointed to the case nozzle joint as a very serious possible problem. NASA's redesign team is working pretty hard on it. Recently, they have begun to look at essentially what you would call metal o-rings or metal rings to replace the polymer/elastomer joints of rings. This may prove to be a great advantage, especially in that case nozzle joint, which concerns us still in the redesign effort.

If that's the case, that might not come on for the first firings, but it could add a great deal if it proved out. There are other examples of that, the offset design, the bolted design, and I think it is very important for us to have a continuing development program and not think that we are going to solve this thing at the instance of first flight.

We have to examine the parts after the flight very carefully. We have to continue to think of safety, reliability, costs, every part of it, and we can improve it. That's what happens in a good development program.

Mr. **Nelson**. I agree with you.

Do you have any commentary upon the fact that NASA is saying they could not have it ready to fly until 1995?

Mr. **Stever**. The advanced rocket?

Mr. **Nelson**. Yes.

Mr. **Stever**. I think a lot of the ideas for an advanced rocket, for a completely new rocket, putting in many features, when you tackle that job and try to put it into a realistic operating device and go through all the safety developments, get all of the experience with a complete design, it stretches out quite a bit more than if you say, I can get a new design manufactured very quickly, but that doesn't take into account a lot of the practicalities of getting it on.

A development always has some things that don't go quite the way you want them to go. I think you have to plan for it, if you are going for a complete advanced design, you have to plan for a longer period. On the other hand, some elements of substantial improvement might come in in a much shorter period, if you have a concurrent development or a side development and then bring it in.

I personally believe that is the proper way to do an advanced development program. I do think you do have to think big because if the Shuttle really does come back and it is a reliable thing, it is going to be very tempting to continue to use some of the things that might have gotten shifted to the unmanned launchers. A good program would certainly provide for that continuous thing in my mind.

Mr. NELSON. You are satisfied with the testing and certification on the redesign of the SRB?

Mr. STEVER. I'm satisfied that it is going to start and going to go on. I don't know how the results are going to come out. I think there may still be some things that we have to back off and re-do and come back at.

Mr. NELSON. Can you give me an example?

Mr. STEVER. Well, I think first of all, the case joint itself, case field joint. We are not sure how all of those new barriers that have been put in are going to perform, especially if you try them with some intentional damage or flaw in the design, which you should do. You don't want a design that doesn't give a little bit of freedom for some difficulties. You like to introduce some flaws and have it still succeed. That's what is called a forgiving design. I don't think any technology development should proceed very long without a forgiving design. If it has a forgiving design and if it is manufactured properly, and if it is operated properly, assembled and operated properly, then you have a safe and reliable system.

I think that we may find some surprises there when we get to the full scale testing. Full duration and full scale testing is where we are going to really begin to learn things about the reliability and the performance.

Mr. NELSON. You are saying really there are going to be some surprises when they do the full up test on the redesigned SRB?

Mr. STEVER. I hope not, but I think it would be very imprudent not to expect them. That is one of the reasons our panel has always been for concurrent alternate designs. Now, NASA, I think, under the pressure of getting a baseline accepted, has not been able to put enough attention to that. They are coming back to put more on. For example, I mentioned the equivalent of a metal o-ring and that, we think, is a very important thing to investigate. There are bolted joint designs. There are alternates to the way the insulation is bonded in there. There are a few alternates to whether or not you put other materials in that path all the way through those barriers to the outside, whether you fill some of those gaps with something.

There are several alternates that should be available to try if we find some questionable feature of the redesign in the testing program. Hopefully, it will go sailing through and everybody will think it is fine, period, without any trouble, but there is a chance it won't.

Mr. NELSON. Mr. Packard.

Mr. PACKARD. Where do you see in the mid-1990s, when, if all goes the way that we would like, we have a mixed fleet, of ELVs and Shuttles, four Shuttles and a sufficient number of ELVs? Where would the scheduling pressure be? On the ELVs or on the Shuttle?

Mr. STEVER. I think to the net period you are mentioning, there are going to be scheduling pressures on everything we have to carry anything. I believe that is the case.

Dr. David mentioned something very important related to this question. He said that the ELVs do not have as much attention to safety and reliability, not as much attention is paid to their development as it is with the manned flight.

Mr. PACKARD. Understandable.

Mr. STEVER. That means that those ELVs will have to go through rather stiff development and testing and verification programs to bring them to where people will trust them also. He pointed out the expense of the payloads that may shift people back to the Shuttle, if the Shuttle is successful. It certainly would be my choice if I had an expensive payload, even though it wasn't a manned payload.

Mr. PACKARD. The reason I was asking was to lead to a further question. Is there any possibility or interest in combining the capabilities of the ELVs with that of the Shuttle, so that you could put up say on ELVs, if there is significant pressure on the Shuttle capabilities, manned needs, to launch payload and at the same time you have already got the Shuttle in space, and have the Shuttle service those payloads that are brought up on an ELV and thus, increase the amount of man required payload into space?

Perhaps the need would never arise. I was wondering if there is any thought to combining the two launch vehicles but servicing all of them with the manned vehicle while in space.

Mr. STEVER. I think that if we redeveloped the Shuttle so it is a very successful, reliable operation, and if we get the ELVs to a point where they perform very well, I think you are going to be besieged with all sorts of combination ideas, especially if we get back to where we are more enthusiastic about space flight, its safety and everything like that. You are going to find people putting together all sorts of systems proposed right along that line.

Mr. PACKARD. You understand my question? In other words, you perceive nothing to inhibit us from looking in that direction?

Mr. STEVER. Why we shouldn't have a mixed fleet, cooperating on some missions, I see no reason why we shouldn't.

Mr. PACKARD. Thank you. Thank you, Mr. Chairman.

Mr. NELSON. Before you go, and I know we need to excuse you momentarily, I want to make sure that there is not something left unsaid here with regard to the fixes on the SRBs. Are you suggesting any additional fix that we ought to be doing?

Mr. STEVER. We have suggested alternatives which offer promise, slightly longer time development, to come along in case the testing program proves these fixes are not as good as we think. First of all, a solid rocket is something that was selected for one reason, it was simple. It's not simple. It's not low technology. It's a high technology, very complex device. Furthermore, a lot of the design depends upon experience and testing as opposed to taking some formula and working it out.

With respect to the cases, how much they will expand in each pressurization, how many pressurizations you have to have before you say they aren't going to expand any more, that they are settled down, that is more understood.

When you try to combine the metal cases and the insulation and o-rings, polymers, bonding materials, to put insulations together, in systems that it is very difficult to measure that so-called circumferential flow in the space between, experience is what we have to go on, and that is why the testing program is so important. It's a little harder to predict this kind of thing.

One other thing; the solid propellant rocket is entirely different from most technological developments in that you cannot test the flight article. You always have to remember that. A technological system fails for those three reasons. It doesn't have a forgiving design. It isn't manufactured perfectly or it isn't used properly.

The 51-L failed for two of those reasons. It was misused and it had a non-forgiving design.

The only way you can have confidence in a rocket, a solid propellant rocket, is to get experience; fire more than one; fire several; inspect them; keep the program going. It is so different from a liquid propellant rocket. After all, a liquid propellant rocket is actually tested for three seconds before it is let go. The rocket that is fired can be tested 20 seconds on the test program before. You can't do that with the solid propellant rocket.

You have very special conditions, first for design, second, the manufacture, third, the operation, and you have to make sure you are perfect in all of them.

Mr. Nelson. Thank you, Dr. Stever. We appreciate it very much.

Mr. Stever. I enjoyed it. Let me wish you the best in a very difficult job you have here. It's very important.

Mr. Nelson. It is a tough year with all the budgeting constraints and so on.

Mr. Stever. For everyone.

Mr. Nelson. Yes, sir.

General, thank you for being so patient.

STATEMENT OF MAJ. GEN. JASPER WELCH, CHAIRMAN, NASA ADVISORY COUNCIL TASK FORCE ON ISSUES OF A MIXED FLEET

General Welch. You have important business, Mr. Chairman. I am happy to be able to try to help.

The members of my Task Force on the NASA Advisory Council, which is its governing body, appreciate the opportunity to be here and share with you our work over the last six or seven months.

I have a few remarks which I think will help in connecting the work of our group and particularly to the testimony you have had before, if I might.

First, there was in parallel with our work an internal NASA staff work headed by Mr. Branscombe on issues of mixed fleet as well. We did work with them. We learned from them, they reacted to us, and we do endorse their findings--I wanted to describe that—with a number of reservations that go, in a sense, beyond their considerations, and those reservations have to do with planning for, making preparations for the inevitable unscheduled delays associated with space launch.

That issue, which Dr. David mentioned, really is at the center of our concerns because we were concerned with the longer-term issues of a space program, a space program the nation can be proud of, and that inevitably requires that the space launch be a robust something you can count on, on the small and then the large. We were not satisfied that the space launch program in the past has had those characteristics, and we observed a number of manifestations of that in payload delays and payload abandonments because of those delays.

The cover letter over the report which came from the chairman of the NASA Advisory Council does explicitly call on the Administrator of NASA to submit a supplemental appropriation to the Congress for expendable launch vehicles. I might as a footnote mention that there is a bureaucratic awkwardness to that recommendation in that the administration, in reaction to the Economic Policy Council's efforts to promote commercial space launch activities, did recommend to the President and the President did approve an NSDD which requires NASA to contract for launch services and not for the purchase of expendable launch vehicles per se.

I think that is kind of an awkwardness at the present time and will have to be worked through as a matter of public policy.

We did not perform an independent assessment of the launch rate capabilities of the shuttle as Dr. David's group did. We rather built upon that, so we will say something later about space shuttle rates, but I want to put in that caveat.

We thought that the most important thing was to plan for the inevitable stand-downs. The reality of the statistics are pretty chilling. Normal ELV experience to date is about a three, four, five percent launch failure rate. If you imagine a shuttle which is ten times better than that, then before we get through the buildup and the space station deployment, or just sort of well into the space station deployment, we drop below a 50 percent probability. So you just cannot do anything in the way of public policy with regard to launch services without dealing with the issue of inevitable stand-downs and disruptions.

From a cold, hard transportation business, it turns out that the duration of the stand-down and its frequency is as important in establishing the overall launch rate as the independent launch rate when things are going well, and the mathematics is more complicated than we ought to deal with here, but the issue is clear, and that is you must spend basically a comparable amount of time, attention and resources in trying to figure out how you are going to deal with these stand-downs, what you can do to be prepared to return to service quickly, and to know what went wrong. Money on instrumentation, money on alternatives, in the wings, if you will, to suspected or worrisome problems.

So that we would say that you must balance your resource expenditure between achieving flight rates when things go well and the prompt restoral of service when things do not go well.

We would like to sensitize the space launch community to the problems of the users. Today and in the past, the user community has basically been told, well, hang around and we will get you off when we are good and ready, and all of those costs have been borne by the user community, who is basically a helpless community. They have no voice in the policies that govern the establishment of their launch services, and we thought that is bad public policy and called for an end to that.

We particularly noticed that the Federal Government has a fiduciary responsibility in this regard because many of those space payloads, in science and technology, in particular, are generated by universities and other non-Federal institutions, some of them public, private monies, and not only is there Federal money into those programs but there is substantial resources in the way of faculty, buildings, support, scholarships to both the students and the faculty and researchers in the private institutions.

The Federal Government, by and large, ought not to be in the position of imposing costs on those users willy-nilly. They have a responsibility to maintain schedule. On the other hand, the users ought to do a better job of preparing themselves for these inevitable stand-downs instead of sitting around wringing their hands.

If I were in a space astronomy program, I should recognize that my telescope there may or may not go exactly when planned, and I ought to prepare to have a solid academic program even if there are delays. So both sides can benefit from realism.

Next point. We did talk about a robust 12 launches of the shuttle per year. What do we mean by robust? What we mean is we were worried about a self-fulfilling prophecy. That is that the budget, green eye-shaders looking at Dr. David's 12, would finance 12, which wouldn't really be quite 12. They would get nine. Then the next year they would say, well, you only flew nine, we will finance you for nine. Next year there won't be enough spares, and they will fly seven, and it just keeps winding on down.

The point is that once you miss a little bit of time, you have got to rush like the dickens to catch up. So we suggested that the right way to do the logistics is to resource for a 16 per year flight rate, with the logistics in place for 16, at least a couple years lead time ahead. Promise 12, manifest for 12, and then you are in a position to take the precautionary stand-down and get back on schedule in a few months.

Mr. NELSON. That seems like a common sense way to do it.

General WELCH. Yes, sir, but I am here to report that that is different than past practice on both sides, both the resourcing and the schedule.

With regard to the workload for the shuttle, first let's recognize we have no other manned space flight vehicle. None in the wings, none planned, none even on paper. That is a reality which will be with us through the end of the century, like it or not. Therefore, it is special and it ought to be treated as special.

Second, in the near term there is more than enough work for shuttle even after you off-load everything you can. Branscombe's study, for example, treated this so-called 130 payloads. What is not said is that that comes after the DOD has taken all they can and put on theirs. It comes after most of the commercial launches are told to go find their rides somewhere unspecified. It comes after 28 shuttle bays full of scientific and space applications programs were abandoned never to be seen again. And it comes after the remaining space science payloads were delayed an average of three years on the current return to shuttle flight schedule. So there is plenty to do in the short run.

In the far term we found that the space station has not yet in its planning reacted to the realities of the space launch situation, and we called very explicitly for a revisiting of the space station plans for space transportation, and in particular, Mr. Packard, that is a golden opportunity for a manned and unmanned launch of what are basically manned equipment. That is currently not in the baseline for the space station. It basically now has all shuttle flights.

In the far term we also recommend that DOD basically get off the shuttle except where they have to be on it for manned things. That is in spite of Dr. David's very good point that the shuttle may wind up being the most reliable way to get to space.

Now, that leads us to the question of 1987. 1987 is a watershed year for planning in space launch services. There is a whole generation, as it turns out, of national security payloads being laid down and plans being laid for them this year. The whole baselining of the space station is coming this year. Our whole set of attitudes and plans with regard to new orbiters, facilities, logistics for the space shuttle will be settled this year, and our general public policy with regard to expendable launch vehicles will be scheduled this year.

It is just a tremendous time, and our actions this year will cast a very long shadow on tomorrow. If we act unwisely, I think tomorrow we may find ourselves having only the memory of the space program.

Among the things which we would put on the table for 1987 is a heavy lift expendable launch vehicle. We believe that there is an urgent need for that, and although we did not look at wide ranges of alternatives, we would say that there are two very good reasons for having an early rather than a later arrival of that vehicle.

The first is to help the space station. If it is to maintain anywhere near its current schedule, then we need to get on with the heavy expendable launch vehicle, probably derived from the shuttle, at the earliest possible time. The estimated costs of that development are commensurate, in our view, with the space station being its principal basis.

Now, the current estimates for the non-recurring engineering are in the neighborhood of 10 percent of the current estimates of the space station program. It is not too high a premium to pay as the principal author. It would be amortized over more than the space station, to be sure, but they would seem to us to have a reasonable basis to say that.

Second, and outside of our charter but as a personal observation on my part, I think that if we are to keep pressure on the Soviet Union with regard to our space program in general and space-based defenses in particular, then a heavy lift launch vehicle is a very, very effective way of demonstrating our commitment to that, and it has the happy feature that it is totally useful aside from the national security program, but it has the benefit of being the most important thing that we could start.

See, we know we know how to do that. You don't know you know how to do some of these other things.

With regard to commercialization, Mr. Packard, our committee—which I must admit is heavily experienced in a non-commercial approach to space launch, and I will say that up front—said two things about commercialization of launch services. First, we ought to go try and do it. We see no reason not to do it. We think it is quite proper to make the government facilities available at the lowest cost you can imagine doing it.

We stopped short of suggesting outright subsidization, but not very strongly stopped short. On the other hand, I must say that we would not offer a great deal of encouragement with regard to the commercialization solving much of our shortfall over the next decade, so it is a two-sided story. I wish them well but I don't predict a great deal of progress in that regard.

I might close by touching briefly on the eight principal recommendations, just to go through those you have. First, the shuttle must be recognized as a national resource and that NASA policy should evolve—an important choice of words—from one that has maximized the use of the shuttle, that has run it as fast as it can, to a policy that preserves the shuttle for those missions requiring its unique capabilities.

Point two, NASA should on a most urgent basis initiate a program to incorporate a diversified family of expendable launch vehicles so that you always have two ways to get there. To include a heavy lift ELV, payloads should be off-loaded from shuttle onto ELVs whenever possible, is the word. NASA planning should be based on a robust 12 shuttle flights, to include buying the fourth orbiter, putting up spares, buying the logistics necessary to carry 16 if all goes well.

NASA planning should be modified to accommodate unexpected precautionary stand-downs for all manned and all unmanned vehicle types. The sizing of the ELV and STS procurements should reflect this realism. Additionally, develop a program and fund it to substantially accelerate recovery from the inevitable stand-downs.

Fifth, and I haven't mentioned this, the Secretary of Defense and the NASA Administrator should develop and sign a new memorandum of understanding which defines the relative roles, responsibilities and authorities of DOD and NASA elements, which is to say all the way down the chain. In the development, procurement and management of common use launch systems, the relationships there are going to get involved with each other very, very tightly in the foreseeable future, and it is very important that nothing be left to chance with regard to friction between the two agencies.

Six, a study should be initiated to evaluate the constraints imposed by the current complement of launch pads and integration facilities on launch rate, surge, absorption of delays and so forth. We did not find that such staff work about what could be done, what might be done, what needed to be done existed, so we were unable to make a recommendation with regard to do this or do that because we didn't have the basis for it.

Seven, a study should be undertaken to evaluate the robustness of the upper stage vehicle fleet to exploit the fully-diversified launcher family. That is a euphemistic way of saying if you do build a heavy lift launch vehicle, you need a new upper stage beyond those currently planned to fully exploit its capabilities.

Eight, the government should encourage commercialization activities but not directly subsidize them.

Mr. Chairman, that ends my remarks.

Mr. **Nelson**. Thank you.

Mr. Packard?

Mr. **Packard**. Thank you, Mr. Chairman. I appreciate all the witnesses. This has been a meaty hearing. I appreciate all the witnesses, and you, too, General.

Beyond the loss of life and equipment as a result of the *Challenger* accident which, of course, was a devastating loss, there has also been, I think, one additional tragedy as an aftermath of the accident, and that is the terribly long and painful delay of the entire space program. It's obvious that it's going to be at least two years before we get back after the accident into space. No one before, I don't think, in NASA or in the entire program would have ever predicted that there could have been an accident severe enough to have delayed us that long. Even at the time of the accident, we never dreamed it would be this long before we would get back into space. And perhaps the—to compound that tragedy is that we did not have any alternative program in conjunction with the shuttle program that allowed us to continue our space exploration during the shutdown of the shuttle.

Now the shuttle, if there had been an accident, interestingly enough, of—the gentleman, Dr. David, indicated that—no, it was Dr. Stever had indicated that there were, in his judgment, three concerns that could lead to an accident, and one was a lack of a forgiving design, and I think one of them was flawed design, and the other was misuse of the equipment, and that two of these were used to—or experienced, that brought about the accident.

Most accidents, if it's a matter of misuse of the equipment, does not cause us to shut down for as long. In other words, it doesn't bring us back to redesign criteria and other problems with the equipment. But if we were—if we were to get to a point where we were at the optimum program, where we had a balanced program, what would that balance consist of that would prevent long shutdowns after equipment or flawed equipment or lack of forgiving design problems or accidents, so that we could still continue? And you have mentioned the heavy lift vehicle as an alternative that we don't even have on the drawing boards at this point. You have left out the space plane. I think the space plane will play a role in our space program as a light launch vehicle compatible with airports and traditional aviation. A fleet of ELVs—and, of course, Orbiters. Where would you see a balance if funding were not the deterrent that say near the end of this century, we would be able to have a space program where we would not experience long shutdowns after an accident—God forbid that we ever have another one. I think one of the concerns that's been expressed in our hearing this morning is reliability of our fleet. What would be the balance that you would feel compatible to an optimum space program for this country?

General **Welch**. Well, I think that you can get to it in the following way. I would start by looking at the missions that are being served by the launch services, and for each of those missions, you have to look and say, okay, what kind of an interruption can that mission—be it space astronomy, solar system exploration, missile warning, in the case of DOD, commercial satellites—what kind of delay could be tolerable for each of those missions? And you will get a different answer for them.

For example, in the communications satellites, what you find is you've got a whole constellation up there, they last for 10 years, and so one could probably, on the average, expect without—this is just a plausibility argument, just to be clear about what I'm saying—an interruption of replacement of those satellites of two, three years would be tolerable, if not optimum, from the mission point of view.

And then for those that really cannot stand a long delay, then they ought to have and prepare to have two ways to get to space. Now we looked at the statistics of the stand-downs from expendable launch vehicles, and they range from a—there have been many such stand-downs over the last 25 years. There have been—they range from the shortest was about two or three months, the most were—the longest was about eight months, and they generally averaged around six or eight months. And that tends to be sort of the cycle it takes really to do the sociology of the matter, as much as the technology of the matter. Find something, figure out what went wrong.

The current shuttle delay is quite long, for two exacerbating—three exasperating reasons:

First off, there was not a lot of planning associated with thinking through what would happen if you had a stand-down. But secondly, the—we had run very thin, very thin development program, and the alternatives to the seals were not in an advanced development program. There was no ongoing advanced development program of the type Dr. Stever is recommending, was not going on. So there were not alternatives developed and on the shelf, ready to exploit.

And the second is, I think, that we—it would solve the first, just a big piece of bad news, and there were a lot of unfortunate concerns about the health and institutional relationships that got mixed in with it.

So I think that the thing to do is basically to have two ways to go to space for every mission.

Mr. Packard. Do you think that's doable?

General Welch. I think that's quite doable, and we looked at some of the practicalities of that, and you can't sort of bring your payload down to the Cape and look around and say are you ready, are you ready, I'll take this one and let's fly Tuesday morning. It's not quite like, you know, finding another flight when you're at the airport when you go there.

But we found that you—for even complicated payloads, you could maintain an alternate launch for not a lot of premium. Up until just a very few months before launch, much closer to the launch date than we had previously been led to believe.

Mr. Packard. How much more? Has there been any annualization up to the—how much more it would cost to maintain a dual launch program?

General Welch. There has been no systematic budget estimates on that on an overall basis. But I would leave you with—you should take away, I think, I would advise you to take away the impression that the answer is not much. Far less, in our view, than the alternative costs which are what do you do when you have to stand around and wait. Those costs are very real, and not in anybody's calculations heretofore.

Mr. PACKARD. One last question, Mr. Chairman. Do you think that the space station will require a dual launch program, or could it be done with a single launch program?

General WELCH. I would not advise going forward with a single launch program on the space station.

Mr. PACKARD. With the what?

General WELCH. Space station. As with a single vehicle, single mode of getting there.

Mr. PACKARD. What role do you anticipate at this early stage that the space plane will play in our total space program?

General WELCH. As part of the—the committee did not examine the space plane, and so I will give you a personal view on that. And I am familiar with the space plane, I served on the advisory board on that.

I believe that it is premature to make any judgment in that regard at the present time.

Mr. PACKARD. Thank you, Mr. Chairman. Thank you very much for your testimony, General.

Mr. NELSON. With regard to the heavy lift vehicle as a possibility of getting part of the space station up, do you think that NASA could undertake that kind of project now, given all the other things that it has on its plate?

General WELCH. Yes, sir.

Mr. NELSON. Do you think it ought to be a joint NASA-Air Force——

General WELCH. Yes, sir.

Mr. NELSON. You are saying then don't leave it to the Air Force to do? Make it joint?

General WELCH. I think that's very important. Very important. You see, there is an enormous resource in NASA which the nation badly needs to put to its best efforts. And that resource is generally populated by people about my age, who have not all that long to go, and it would be a pity to have them just fritter away their last mature and best years.

Mr. NELSON. So you tend to think that a shuttle-derived design for heavy lift is the way to go as opposed to the Air Force's wanting to design something from scratch?

General WELCH. I wouldn't choose between those children. My advice has been—and this is my personal advice, the committee did not go this far—my personal advice to both the Air Force and to NASA has been that I believe that one program office could very efficiently manage two vehicles, one of which is near term, and I would use that word rather than shuttle-derived, and one of which is long term, and meets other criteria. And the long term criteria are primarily associated with efficiency of operation, and great attention to automaticity, and getting the—you know, getting the people, the ground army, under control. And that really is hard to do. I have worked a great deal on logistics and R&M in my time in the Air Force, and I am here to tell you that's—that takes work. You don't just order it up.

So I think that you could have a joint program office. I believe it could be charged to develop two vehicles, one available early and one available late, and with slightly different program.

We have a lot of experience in that. I might bring to your attention the experience in Mr. Skaggs' district, where the Martin Company bid on the small ICBM for the integrating contractor for the small ICBM, bid that competitively, and bid at a price which was less than half of the government's estimate, and almost less than half of its nearest competitor on a program of a billion dollars or so, arguing that because they had the large ICBM, the MX integrating contract, that they could do the small ICBM with the same work force very efficiently. And so they have it broken down to exact—down to the level of, you know, I've got five guys doing the big one, and it will take just two more to do both of them. I—and there is another—there are several other examples of that, and these are real economies of scale, this isn't just playing around, and——

Mr. **Packard**. Excuse me, Mr. Chairman. Is that an argument for single source?

General **Welch**. No, it's for a single program office. No, no, no, it's not an argument for single source at all. A single program office. And for a single integrating contractor.

The space business and the high tech business, you've got to be really careful. I mean costs are—costs are in the paper, not in the metal.

Mr. **Nelson**. Was that Martin contract that you were talking about, was that a fixed price contract?

General **Welch**. Yes, sir.

Mr. **Nelson**. Do you have any advice to us about acquisition of launch services as opposed to buying ELVs, or does it make any difference to you for NASA?

General **Welch**. Well, we actually said something about that in the report, and what we said is that whatever may be right in the long term, we wouldn't rock the boat in the near term. And it's said more eloquently in the report, but that's the heart of the matter. And we just don't think that now is the time for experimentation with regard to procurement policy. And as I say, we're oldtimers, and some people may—and probably should—discount our—the emotion in that remark. I do not think they ought to discount the substance of it. [Laughter.]

Mr. **Nelson**. Are you encouraged by the recent spate of reservations for both Martin and McDonnell on their commercial ELVs?

General **Welch**. Oh, I think that those commercial ELVs are likely to really work. You see, there's a situation where—and we anticipated those, I think, is what I would say. We said, look, any time when you've got a big fixed buy from a well-heeled customer, probably the government, the tag-alongs are likely to come fairly dramatically.

Mr. **Nelson**. Mr. Packard, do you have any further questions?

Mr. **Packard**. I'm through, thank you, Mr. Chairman.

Mr. **Nelson**. General—oh, I'm sorry, Mr. Skaggs. We were sitting here talking about you, your district, your state.

Mr. **Skaggs**. Then I'd like equal time. [Laughter.]

Thank you, Mr. Chairman.

I was interested in your observation about young men of your age who are about to go into other pursuits, and that we ought to take advantage of your expertise and experience before it's too late.

Does that imply that the next generation within NASA has really grown up with the shuttle program to the extent that its disposition toward ELVs and a mixed fleet is significantly biased and resistant to that?

General Welch. No, that's—that was not anywhere near my thought processes.

Mr. Skaggs. Well——

General Welch. I was just observing the demographic statistics, is all.

Mr. Skaggs. You're not vain. Do you sense any—what is the attitude that you sense within NASA with regard to a shifting to a mixed fleet approach? Is it welcomed? Is it resisted? Is there——

General Welch. It's novel. It's novel.

Mr. Skaggs. And therefore——

General Welch. Oh, I've been told by everybody who seemed to count for 20 years that an exclusive commitment to the shuttle was in the national interest, and they sort of got used to that, and all of a sudden people are saying, well, you know, why were you so dumb as to do that? And I must say I think they have a certain point to say, you know, we got told to do that to a large extent. I don't mean the rank and file did.

Mr. Skaggs. How long will it take for that training to be undone, if you will?

General Welch. Well, I think it will all go away as soon as they have another program. You know engineers, they'll rally around the current program as long as it's supported and funded. Right now, ELVs for NASA is a nonprogram, as we all said that around here, and as soon as there is a real program, they'll be off and running on the new program.

Mr. Skaggs. I don't have a chairman to thank. Thank you.

In the absence of Mr. Torricelli, I take it upon myself to inquire of witnesses about second sourcing, and just wondering what your view is on that with regard to the SRB in particular.

General Welch. We didn't look at that at all. And I have no personal knowledge of the matter, one way or another. I'm sorry.

Mr. Packard. General, while we're waiting for the Chairman to close, what is—do you have an opinion on whether we ought to maintain an Atlas program or something, those programs that do not have a government contract?

General Welch. I'd like to punt on that one.

Mr. Packard. All right. I'll let you.

Mr. Nelson. Thank you, General. It's been a good discussion. We appreciate it.

The meeting is adjourned.

[Whereupon, at 12:30 p.m., the subcommittee was adjourned.]

APPENDIX 1

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of

April 24, 1987

Honorable Bill Nelson
Chairman, Subcommittee on Space
Science and Applications
Committee on Science and Technology
U.S. House of Representatives
Washington, DC 20515

Dear Mr. Nelson:

This is in response to your letter of April 15, 1987, inviting me to testify at hearings being conducted by your subcommittee regarding the Space Shuttle recovery effort.

As you know, I will be unable to be with you at that time. However, Mr. Norman R. Parmet, the Aerospace Safety Advisory Panel Deputy Chairman, along with six members/consultants of the Panel will be representing me and the full Panel at the hearing. The prepared testimony is, of course, provided for the record.

I would like to provide you with my up-front comments which I would have used as my oral statement.

I assumed the Chairmanship of the Aerospace Safety Advisory Panel late last year. Most of the work of the Panel for 1986 and early 1987 was performed under the direction of Mr. Norman R. Parmet, the Deputy Chairman under the former chairman, Mr. John C. Brizendine.

A little over a year ago the national tragedy of the Challenger accident occurred. The recovery program to continue Space Shuttle flights is well underway--but the next flight will not occur until sometime next year--a hiatus of more than two years in Space Shuttle operations. Since early operations will clearly be of a testing and experimental nature, the flight rate will not be that of a "going" program. The absence of a clearly articulated national commitment to space development and exploration in conjunction with the availability of alternative launch systems has created a situation where NASA could be tempted to rush the Space Shuttle back to flight status. The viability of the Space Shuttle System would be at great risk if the program were to incur another delay such as that caused by the Challenger accident.

NASA's recovery program encompassing reorganization, responsibility redefinition, redesign efforts, testing programs, safety and quality organization responsibility definition and analyses, and redefinition of operational requirements and procedures are for the most part in place and taking place.

Although this work is not complete by any means it is being accomplished within the scope of recommendations of the Presidential Commission on Space Shuttle Challenger Accident and the House of Representatives Committee on Science and Technology Investigation Report.

The recovery program is viewed as acceptable by the Panel. However, it is important that the planned work continue to completion. The analyses, redesign, testing and other activities which have not moved out of the planning stage into the "hardware" stage should not be "short changed." Again, "safety first; schedule second."

The current efforts of the Aerospace Safety Advisory Panel are to advise and assist NASA and its contractors in their efforts to finish the recovery task. This does not mean that all our work reviewing the adequacy of other safety and performance improvement design changes or procedures will cease. Development and testing will always reveal that some changes and improvements are desirable. The Aerospace Safety Advisory Panel will foster those things that will ensure that NASA has the opportunity to properly conduct, particularly with regard to safety and mission success, the Space Shuttle recovery and future efforts.

Our comment on the philosophy of "have we done all we need to do to insure safety for first reflight" is "safety first; schedule second."

Again I want to assure you and the members of your committee that we will continue to act as your "eyes" and "ears" in our mutual desire to provide safe access to space. I would appreciate the opportunity to meet with you and your colleagues whenever practical to continue to respond to your goals of: what things are NASA doing well? In what areas does NASA need to improve? Specifically, what changes should NASA make to achieve these improvements? and what actions should your committee take to ensure that these changes are adopted by NASA?

Sincerely,

Joseph F. Sutter

Joseph F. Suttter
Chairman, Aerospace Safety Advisory Panel

APPENDIX 2

NASA

National Aeronautics and
Space Administration

Washington, D.C
20546

Reply to Attn of

May 20, 1987

Honorable Bill Nelson
Chairman, Subcommittee on
Space Science and Applications
Committee on Science and Technology
U.S. House of Representatives
Washington, DC 20515

Dear Mr. Nelson:

Many thanks for your letter of May 15, 1987, regarding the Aerospace Safety Advisory Panel's participation in your Shuttle recovery hearing on April 29, 1987. Mr. Norman R. Parmet, Deputy Chairman, has asked me to respond to that letter.

In response to the two questions posed by one of your members concerning our "Lessons Learned" report you will find a very brief answer here and more details in the attachment to this letter.

1. How widely did you disseminate your subsidiary "Lessons Learned" report within NASA?

Response: The "Lessons Learned" report was distributed throughout all of NASA Headquarters, NASA Centers, NASA contractors and other individuals who had requested it. A total of more than two hundred (200) copies were distributed, and the ASAP staff office continues to receive requests for it. The distribution breakdown was (approximately):

NASA Headquarters	60	NASA Johnson Space Center	15
NASA Kennedy Space Center	20	NASA Marshall Sp. Flt. Ctr	15
NASA Anes Research Center	4	NASA Langley Res. Center	4
NASA Lewis Research Center	4	NASA Goddard Sp. Flt. Ctr	2
NASA Jet Propulsion Lab	4	NASA Dryden Flt. Res. Fac.	2
NASA Nat. Space Tech. Lab.	2		
	TOTAL		132
Prime Contractors (STS/SS)	30	News Media	20
General Accounting Office	2	Other Aero. Contractors	15
Individuals	10	Miscellaneous	4
	TOTAL		81

2. To your knowledge, have NASA managers distributed this report to all employees in a manner that assures that it will be read and understood at all levels?

Response: At NASA Headquarters the report was provided to technical employees (engineers and technical managers) particularly those in the Safety, Reliability, Maintainability and Quality Assurance (SRM&QA) organization, Space Transportation System, and the Space Station. Lesser numbers were provided to non-manned space flight managers and engineers (for example, Aeronautics research and development personnel). It is our understanding that all Center SRM&QA managers have made a point of having their personnel aware of the report's content. Examples of contractors use are the Boeing Aerospace Corporation located in Huntsville, Alabama who upon receipt of the report reproduced about 100 copies and distributed with instructions to read and apply them to all engineering personnel, and the Lockheed Shuttle Operations Corporation (the Shuttle Processing Contractor) located at Kennedy Space Center who set up a special task team to assure the reading and application of the Lessons Learned (see enclosure).

Again, thank you for your support of the Aerospace Safety Advisory Panel as its members and consultants continue their efforts to support a timely and safe return to Space Shuttle flight. We look forward to meeting with you and/or your staff as conditions warrant.

Sincerely,

Gil Roth

Gilbert L. Roth
Staff Director
Aerospace Safety Advisory Panel

Enclosure

Lockheed Space Operations Company

1100 Lockheed Way
Titusville, Florida 32780

In Reply, Refer to: RBD87-5001-006
9 January 1987

National Aeronautics and Space Administration
Washington, D. C. 20546

Attention: Gilbert L. Roth, F6133
Mail Code LB

Subject: Lessons Learned - An Experience Data Base for Space Design, Test and Flight Operations, November, 1986

The SPC has received copies of your November, 1986 Lessons Learned report, entitled "An Experience Data Base for Space Design, Test and Flight Operations."

To assure that the lessons learned and recommendations outlined in your report are expeditiously reviewed and applied throughout the SPC, a matrix has been developed assigning actions to appropriate Directors. Assigned actions will be monitored and tracked to closure.

We will be prepared to provide you with a briefing to status the disposition of our actions at the next ASAP meeting at KSC, if desired.

LOCKHEED SPACE OPERATIONS COMPANY

Ray B. Davis

Ray B. Davis, Director
Safety, Reliability, Maintainability
and Quality Assurance

C: R. Sieck, GM
J. Thomas, GO

LOOK TO LOCKHEED FOR LEADERSHIP

ASAP LESSONS LEARNED MATRIX

ITEM	RESPONSIBLE ORGANIZATION	IMPACT ON SPC		REQUIRED ACTION
		YES	NO	
1. INTRODUCTION Pages 1-3	Primarily NASA HQS, with direct impact on all NASA Centers		X	None Information only
2. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS				
a. Roles, responsibilities and relationships Pages 3-5	NASA HQS and NASA Centers	X All 1st line Directors		Review, information and application of lessons learned and recommendation.
b. STS Technical Audit Process Pages 5-6	NASA HQS and NASA Centers	X All 1st line Directors		Review, information and application of lessons learned.
c. The Funding Trap Pages 6-7	NASA HQS and NASA Centers	X All 1st line Directors		Review, information and application of lessons learned.
d. Aggregate Risk Pages 7-8	NASA HQS and NASA Centers	X All 1st line Directors		Review, operations to assure that lessons learned are adequately applied.
e. Design Management Pages 8-9	NASA HQS, NASA Centers and NASA Contractors	X H. Lamberth		Review lessons learned and recommendations to assure that organizational policies and procedures incorporate th findings in this category.
f. Problem Reporting and Corrective Action System For Ground Support Operations Pages 9-10	NASA HQS, NASA Centers and NASA Contractors	X R. Davis		Review and application of lessons lear ed and recommendations.

ASAP LESSONS LEARNED MATRIX

ITEM	RESPONSIBLE ORGANIZATION	IMPACT ON SPC		REQUIRED ACTION
		YES	NO	
g. Achieving Adequate Safety Levels Pages 10-13	NASA HQS, NASA Centers and NASA Contractors	X R. Davis		Review and disseminate findings to appropriate Directors for application of lessons learned.
h. Designated Engineering and Quality Representatives Page 13	NASA HQS, NASA Centers and NASA Contractors	X R. Davis H. Lamberth		Review and application of lessons learned and recommendations.
3. GROUND EQUIPMENT AND FACILITIES				
a. General Pages 13-14	NASA KSC, NASA KSC Contractors	X P. Yount		Review and application of lessons learned and recommendations
b. Welding Pages 14-15	NASA HQS, NASA Centers and NASA Contractors	X P. Yount H. Lamberth R. Davis G. Savage		Review and application of lessons learned.
c. Hoist Systems Page 15	NASA HQS, NASA Centers and NASA Contractors	X P. Yount H. Lamberth R. Davis		Review and application of lessons learned.
d. Procedures Pages 15-17	NASA HQS, NASA Centers and NASA Contractors	X All 1st line Directors		Review and application of lessons learned. Conduct of appropriate briefings to expeditiously improve this finding.
e. Integrated Design and Modification Concerns Pages 17-19	NASA HQS, NASA Centers and NASA Contractors	X H. Lamberth		Review and application of lessons learned.
4. FLIGHT HARDWARE AND SOFTWARE				

ASAP LESSONS LEARNED MATRIX

ITEM	RESPONSIBLE ORGANIZATION	IMPACT ON SPC		REQUIRED ACTION
		YES	NO	
a. Welding Pages 19-20	NASA HQS, NASA Centers and NASA Contractors	X H. Lamberth R. Davis		Review and application of lessons learned.
b. Instrumentation Pages 20-22	NASA HQS, NASA Centers and NASA Contractors	X H. Lamberth P. Yount R. Davis		Review and application of lessons learned.
c. Undersized Wiring and Cable Design	NASA HQS, NASA Centers and NASA Contractors	X H. Lamberth P. Yount R. Davis		Review and application of lessons learned.
d. Hardware Contamination Pages 23-25	NASA HQS, NASA Centers and NASA Contractors	X H. Lamberth P. Yount E. Mathews R. Davis		Review and application of lessons learned.
e. Software/Computers Pages 25-27	NASA HQS, NASA Centers and NASA Contractors	X W. Brett		Review and application of lessons learned.
f. Payloads and Upper Stage Propulsion System Pages 27-29	NASA HQS, NASA Centers and NASA Contractors	X E. Mathews		Review and application of lessons learned in those areas germane to payload processing.
5. SPACE TRANSPORTATION SYSTEM/CENTAUR				
a. Background Pages 29-30	NASA HQS, NASA Centers and certain NASA Contractors		X	Information
b. Establishment of Firm Program Goals Page 30	NASA HQS, NASA Centers and certain NASA Contractors		X	Information

ASAP LESSONS LEARNED MATRIX

ITEM	RESPONSIBLE ORGANIZATION	IMPACT ON SPC		REQUIRED ACTION
		YES	NO	
c. Concurrent Development Pages 30-31	NASA HQS, NASA Centers and certain NASA Contractors		X	Information
d. Integrated Process Pages 31-32	NASA HQS, NASA Centers and certain NASA Contractors		X	Information
e. Safety Process Pages 32-33	NASA HQS, NASA Centers and certain NASA Contractors		X	Information
f. Acquiring Space Qualified Electronic Piece Parts	NASA HQS, NASA Centers and certain NASA Contractors		X	Information
g. Weight and Performance Pages 33-34	NASA HQS, NASA Centers and certain NASA Contractors		X	Information
SUMMARY	NASA HQS, NASA Centers and NASA Contractors	X All 1st line Directors		Review and Application.

Aerospace Safety Advisory Panel

Visit To KSC

April 21-22, 1987

SPACE SHUTTLE

NASA

National Aeronautics and
Space Administration

John F. Kennedy Space Center

KSC FORM 9-114A (REV. 4/77)

AEROSPACE SAFETY ADVISORY PANEL
LESSONS LEARNED

L. B. SPIVEY

25

LESSONS LEARNED AREAS OF EMPHASIS

A. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS

  1. ROLES, RESPONSIBILITIES AND RELATIONSHIPS
  2. STS TECHNICAL AUDIT PROCESS
  3. THE FUNDING TRAP
  4. AGGREGATE RISK
  5. DESIGN MANAGEMENT
  6. PROBLEM REPORTING AND CORRECTIVE ACTION SYSTEM FOR GROUND SUPPORT EQUIPMENT
  7. ACHIEVING ADEQUATE SAFETY LEVELS
  8. DESIGNATED ENGINEERING/QUALITY REPRESENTATIVES

LESSONS LEARNED AREAS OF EMPHASIS

B. GROUND SUPPORT EQUIPMENT AND FACILITIES

1. WELDING
2. HOIST SYSTEMS
3. PROCEDURES
4. INTEGRATED DESIGN AND MODIFICATION CONCERNS

LESSONS LEARNED AREAS OF EMPHASIS

C. FLIGHT HARDWARE AND SOFTWARE

1. WELDING
2. INSTRUMENTATION
3. UNDERSIZING WIRING AND CABLE DESIGN
4. HARDWARE CONTAMINATION
5. SOFTWARE/COMPUTERS
6. PAYLOADS AND UPPER STAGE PROPULSION SYSTEMS

LESSONS LEARNED AREAS OF EMPHASIS

D. SPACE TRANSPORTATION SYSTEM/CENTAUR

1. BACKGROUND
2. ESTABLISHMENT OF FIRM PROGRAM GOALS
3. CONCURRENT DEVELOPMENT
4. INTEGRATION PROCESS
5. SAFETY PROCESS
6. ACQUIRING SPACE QUALIFIED ELECTRONIC PIECE PARTS
7. WEIGHT AND PERFORMANCE

SUMMARY OF ACTIONS

- o ASAP LESSONS LEARNED REPORT WAS DISSEMINATED TO ALL DIRECTORS, MANAGERS, AND SUPERVISORS FOR INFORMATION, REVIEW, AND DISCUSSION WITH EMPLOYEES UNDER THEIR JURISDICTION FOR APPROPRIATE APPLICATION OF LESSONS LEARNED.

- o 1ST LINE DIRECTORS WERE CHARGED WITH THE RESPONSIBILITY OF RESPONDING TO THE FINDINGS AND RECOMMENDATIONS OUTLINED IN THE ASAP LESSONS LEARNED REPORT. THE CONTENTS OF THIS PRESENTATION WILL ADDRESS THOSE ACTIONS TAKEN, ONGOING, OR PROGRAMMED.

A. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS

1. ROLES, RESPONSIBILITIES AND RELATIONSHIPS

RECOMMENDATIONS:

- THE OVERALL "SYSTEM" (NASA AND ITS CONTRACTORS) MUST TAKE THE TIME TO ASSURE THAT EVERYONE IS AWARE THAT THE OLD PHILOSOPHY THAT TECHNICAL EXCELLENCE IS MORE IMPORTANT THAN SCHEDULE HAS NOT CHANGED.

- THE SPACE SHUTTLE IS A DEVELOPMENT PROGRAM -- NOT AN OPERATIONAL TRANSPORTATION SYSTEM -- AT THIS TIME OR IN THE NEAR FUTURE. THIS MUST BE UNDERSTOOD TO ACHIEVE "THE RETURN TO SAFE FLIGHT IN THE SHORTEST POSSIBLE TIME".

- THE PRIMACY OF NASA HEADQUARTERS MUST BE REESTABLISHED IN RELATION TO THE RESPONSIBILITIES AND AUTHORITY -- BOTH FORMAL AND INFORMAL -- OF THE R&D CENTERS. THIS IS A PRESIDENTIAL COMMISSION RECOMMENDATION AS WELL. BEYOND THIS, HOWEVER, IS THE NEED FOR A TOUGH-MINDED LOOK AT NASA'S BASIC INSTITUTIONAL STRUCTURE AND ITS ESTABLISHED METHODS FOR CARRYING OUT COMPLICATED TECHNICAL PROGRAMS. ALTHOUGH IT IS NOT EASY TO CHANGE TRADITION AND VALUES THAT SURROUND EACH OF THE NASA CENTERS (NOR WOULD IT BE WISE TO DESTROY ENTIRELY THEIR LOYALTIES AND COMMITMENTS), IT IS NECESSARY TO DEVELOP OPERATIONG PROCEDURES AND RELATIONSHIPS THAT PERMIT AGENCY-WIDE PRIORITIES TO BE CARRIED OUT SUCCESSFULLY. TO RESTATE A JADED AXIOM: "ONE SHOULD STRIVE FOR A STRUCTURE THAT MAKES THE WHOLE GREATER THAN THE SUM OF ITS PARTS".

ROLES, RESPONSIBILITIES AND RELATIONSHIPS

- TO EMPHASIZE TECHNICAL EXCELLENCE IS MORE IMPORTANT THAN SCHEDULE:
  - ENGINEERING DIRECTORATE ELEVATED TO VICE PRESIDENT LEVEL
  - VEHICLE PROCESSING ENGINEERING AND GSE/FACILITY ENGINEERING PLACED UNDER A SINGLE ENGINEERING DIRECTORATE
  - ENGINEERING DIRECTOR ASSIGNED TO OPF ON A FULL TIME BASIS TO ENSURE ADEQUATE ENGINEERING INVOLVEMENT AND SUPPORT
  - SENIOR ENGINEERS ASSIGNED TO EACH ORBITER TO OVERSEE ACTIVITIES OF ENTIRE TEST TEAM
  - DIRECTORATE OF OPERATIONS CONTROL WAS ESTABLISHED WHICH SEPARATES SCHEDULING FROM OPERATIONS
- ESTABLISHMENT OF THE REORGANIZED ENGINEERING DIRECTORATE AND THE OPERATIONS CONTROL DIRECTORATE WILL ENSURE THAT PROCESSING ACTIVITIES ARE CONDUCTED UNDER THE PHILOSOPHY THAT THE SHUTTLE IS A DEVELOPMENTAL R&D PROGRAM.
- NASA PROGRAM-WIDE RESPONSIBILITY

A. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS

2. STS TECHNICAL AUDIT PROCESS

RECOMMENDATION:

- TECHNICAL AUDIT GROUPS SHOULD BE CONSIDERED BY THE SPACE STATION PROGRAM AS SOON AS PRACTICAL TO ASSURE TECHNICAL SOUNDNESS OF THE DESIGN AS IT MOVES THROUGH THE FINAL STAGES OF PHASE B AND INTO PHASE C/D.

- IT MIGHT ALSO BE FITTING TO CONSTITUTE SUCH AUDIT TEAMS TO ASSESS ROUTINE PROCESSES AND PROCEDURES FOR OPERATING THE SHUTTLE AND SUGGEST NEW APPROACHES WHICH COULD SAVE COSTS WITHOUT INCREASING HAZARDS. KEEP IN MIND THE SUCCESS OF SUCH AD HOC TEAMS STEMS FROM THE CURRENCY OF THEIR TECHNICAL OPERATIONAL EXPERIENCE, THEIR TOTAL FAMILIARITY WITH THE SYSTEM AND THEIR LACK OF DEDICATION TO ANY ROUTINE REPORTING OR DOCUMENTATION DISCIPLINE.

STS TECHNICAL AUDIT PROCESS

- NASA PROGRAM-WIDE RESPONSIBILITY
- NASA PROGRAM-WIDE RESPONSIBILITY. AT KSC THE FOLLOWING AUDIT ACTIVITY IS ONGOING:
  - FMEA/CIL FOR GSE (36 TEAMS)

    335 SAAs WERE REVIEWED

    876 CSFP WERE IDENTIFIED NOTE: ALL 876 CSFP ARE CONTAINED IN 75 SYSTEMS

    100 NEW SAAs ARE REQUIRED AS A RESULT OF AUDITS

    COMPLETION DATE FOR THIS EFFORT IS DECEMBER 1987
  - OMI UPDATES/AUDIT OF WADS REQUIRED FOR 1ST FLIGHT
  - AUDIT OF LAUNCH COMMIT CRITERIA HAS BEEN COMPLETED WITH THE EXCEPTION OF THE MECHANISM SECTION.
  - OMRSD REVIEWS/AUDITS FOR 1ST FLIGHT

    IMPLEMTATION PLAN COMPLETED AND KSC REVIEWS COMMENCED IN SEPTEMBER 1986

    INHOUSE ORBITER REVIEWS (NASA-KSC, SPC AND LSC) COMPLETED IN DECEMBER 1986

    DESIGN CENTER REVIEWS IN PROGRESS

STS TECHNICAL AUDIT PROCESS CONT'D

ET/SRB OMRSD REVIEW COMPLETED

HAZARD REEVALUATION OF ALL KSC HAZARDS IS ONGOING

2292 HAZARDS IDENTIFIED

1174 HAZARDS HAVE BEEN REVIEWED BY TEAMS

874 HAZARDS DISPOSITIONED

SCHEDULE:

PRE-SCREENING BY NASA SAFETY, SPC SAFETY, AND EBON	4/30/87
LEVEL IV SCREENING BOARD	4/30/87
COMPLETION OF TEAM REVIEWS	7/15/87
GROUND EQUIPMENT REVIEW BOARD	9/30/87
LEVEL III CCB REVIEW/APPROVAL	9/30/87
LEVEL II/LEVEL I (SSRB) REVIEW/APPROVAL	10/30/87
HAZARD REEVALUATION COMPLETE	10/30/87

NOTE: THESE EFFORTS ARE TO ENHANCE THE SAFETY OF THE STS PROCESSING EFFORT AND WILL NOT BE CLASSIFIED AS COST SAVING ACTIVITIES.

A. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS

3. THE FUNDING TRAP

RECOMMENDATIONS:

o BEGINNING A MAJOR AEROSPACE PROGRAM WITHOUT THE APPROPRIATE NATIONAL SUPPORT AND RESOURCES COMMITMENT IN PLACE SHOULD NOT BE ATTEMPTED.

o "BUILD - TO - COST" SHOULD IMPLY THAT THE PROGRAM MANAGEMENT WILL MATCH PERFORMANCE AND SAFETY WITH THE RESOURCES AVAILABLE ON A REALISTIC SCHEDULE. SUCH SCHEDULES CAN BE SET AS "GOALS" WHICH ARE ACHIEVABLE WITHOUT BEING COMPLETELY OUT-OF-REACH.

o PROGRAM SPECIFICATIONS AND CONTRACTUAL ARRANGEMENTS SHOULD BE SO STRUCTURED AS TO PROMOTE CONSTANT REASSESSMENTS OF THE BASELINE SYSTEM DESIGN, DEVELOPMENT OF BACK-UP DESIGNS, AND AVOIDANCE OF A SINGLE-MINDED FOCUS ON MEETING STRINGENT INITIAL REQUIREMENTS WHICH EXCEED THAT WHICH IS POSSIBLE. MAINTENANCE OF ALTERNATIVE DESIGNS AND ADHERENCE TO RIGOROUS TESTING SHOULD BE PURSUED TO ASSURE MISSION SUCCESS AND SAFETY.

THE FUNDING TRAP

- ○ NASA PROGRAM-WIDE RESPONSIBILITY
- ○ NASA PROGRAM-WIDE RESPONSIBILITY
- ○ NASA PROGRAM-WIDE RESPONSIBILITY
- ○ NASA PROGRAM-WIDE RESPONSIBILITY

A. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS

4. AGGREGATE RISK

RECOMMENDATION:

- THE CAPABILITY AND FUNDS TO DO AN "AGGREGATE RISK" ARE WITH NASA, BUT IT SHOULD BE A DISCRETE RESPONSIBILITY. IT CANNOT BE DONE BY THE ENGINEERING ORGANIZATIONS AS A PART-TIME EFFORT. INDEED, IT MIGHT BE WELL TO BRING IN OUTSIDE HELP WHO HAVE BEEN INVOLVED IN NUCLEAR POWER PLANT RISK ANALYSES TO PROVIDE EXPERTISE ON HOW NASA SHOULD USE ITS OWN EXPERTISE IN BOTH PROBABILITY RISK ASSESSMENTS AND AN OVERALL AGGREGATE RISK ASSESSMENT. IT SHOULD NOT BE CONSTRUED AS PART OF AN "ENGINEERING DESIGN FUNCTION". IN BRIEF, IT IS SUGGESTED THAT THERE BE A FORMAL EFFORT WITHIN THE PROGRAM (SPACE SHUTTLE, SPACE STATION OR ANY OTHER CRITICAL PROGRAM OR PROJECT) TO QUANTIFY THE AGGREGATE RISK OF THE TOTAL SYSTEM AND THE IMPACT OF THE CHANGES THAT OCCUR TO IT.

AGGREGATE RISK

- THE TOTAL QUESTION OF AGGREGATE RISK OF A TOTAL SYSTEM IS A NASA PROGRAM-WIDE ISSUE. HOWEVER, TO ENHANCE OUR ABILITY TO CONTRIBUTE EFFECTIVELY IN THE AREA OF AGGREGATE RISK, THE FOLLOWING ACTIONS HAVE BEEN TAKEN, ONGOING OR PROJECTED:
  - NASA SR&QA ORGANIZATION REORGANIZED WITH SYSTEM SAFETY, SYSTEM ASSURANCE, AND RELIABILITY UNDER A SINGLE DIRECTOR
  - WITHIN THE SPC, 28 RELIABILITY ENGINEERS AND 16 SYSTEM SAFETY ENGINEERS ADDED TO STRENGTHEN FMEA/CIL, SAA, HAZARD ANALYSIS, AND RISK ASSESSMENT ACTIVITIES
  - SECON ENGINEERING CONDUCTED RELIABILITY ENGINEERING TRAINING FOR NASA AND SPC SYSTEM SAFETY AND RELIABILITY ENGINEERING. AN INTREGAL PART OF THE TRAINING WAS PROBABILISTIC RISK ASSESSMENT METHODS
  - HAZARD REEVALUATION EFFORT IS A MULTI-CONTRACTOR EFFORT AT KSC NASA - ROCKWELL - ROCKETDYNE - MARTIN MARIETTA, SPC, USBI

    NOTE: UPON COMPLETION OF THIS EFFORT, KSC WILL HAVE A QUANTIFIED BASELINE ON ALL HAZARDS
  - REEVALUATION OF ALL CRITICALITY 1 CSFP ON ALL GSE/FACILITIES
  - SAFETY REVIEW OF ALL MODIFICATIONS

A. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS

5. DESIGN MANAGEMENT

RECOMMENDATIONS:

- COMPREHENSIVE CONFIGURATION MANAGEMENT IMPLEMENTED EARLY IS ESSENTIAL FOR ANY PROGRAM, AND PARTICULARLY FOR ONE WITH COMPLEX INTERFACES AND A VARIETY OF HARDWARE AND DOCUMENTATION SOURCES. POSITIVE STEPS MUST ALWAYS BE TAKEN TO ASSURE THAT ENGINEERS BECOME FAMILIAR WITH ACTUAL HARDWARE, DEVELOP AND INTUITIVE UNDERSTANDING OF COMPUTER-DEVELOPED RESULTS, AND MAKE PRODUCTIVE USE OF GROUND TEST AND FLIGHT DATA IN THEIR CONTINUING LEARNING PROCESS, WHICH TO A DEGREE BEGINS ANEW FOR EACH PROGRAM.

- AN EFFECTIVE DESIGN REVIEW MUST EMPHASIZE HARDWARE, BUT SHOULD ALSO INCLUDE THE REVIEW OF HARDWARE IMPACTS RESULTING FROM AMBIENT CONDITIONS AND MISSION-DEVELOPED LOADS. NOT ONLY DESIGN PERSONNEL, BUT TEST AND OPERATIONS REPRESENTATIVES SHOULD PARTICIPATE IN DESIGN REVIEWS.

DESIGN MANAGEMENT

TO ASSURE THE PROPER LEVEL OF EMPHASIS IS APPLIED TO THE ENGINEERING ASPECTS AND RESPONSIBILITIES ASSOCIATED WITH SHUTTLE PROCESSING ACTIVITIES, THE FOLLOWING ACTIONS HAVE BEEN TAKEN WITHIN THE SPC:

- THE DIRECTOR OF ENGINEERING HAS BEEN ELEVATED TO THE VICE PRESIDENT LEVEL.
- THE VICE PRESIDENT FOR ENGINEERING IS RESPONSIBLE FOR BOTH VEHICLE PROCESSING AND GSE/FACILITIES ENGINEERING DESIGN CHANGES.
- AN ENGINEERING DIRECTOR HAS BEEN ASSIGNED TO THE OPF ON A FULL TIME BASIS. HIS OFFICE IS PHYSICALLY LOCATED IN THE OPF FACILITY. HIS PRIMARY ROLE IS TO ENSURE ADEQUATE ENGINEERING INVOLVEMENT AND SUPPORT. THE ENGINEERING DIRECTOR REPORTS DIRECTLY TO THE VICE PRESIDENT OF ENGINEERING.
- SENIOR ENGINEERS HAVE BEEN ASSIGNED TO EACH ORBITER TAIL NUMBER. THESE SENIOR ENGINEERS OVERSEE THE ACTIVITIES OF THE ENTIRE TEST TEAM. THEY ALSO REPORT DIRECTLY TO THE VICE PRESIDENT OF ENGINEERING. THE ROLE OF THE SENIOR ENGINEERS IS AS FOLLOWS:

DESIGN MANAGEMENT CONT'D

  - OBTAIN TIMELY ENGINEERING REQUIREMENTS AND PROBLEM SOLUTIONS FOR VEHICLE PROCESSING.
  - BE A TECHNICAL LEADER FOR THE TEST TEAM
  - BE INTIMATELY FAMILIAR WITH ENTIRE FLIGHT AND GROUND PROCESSING HISTORY OF THE ORBITER THAT HE IS ASSIGNED TO.
  - PARTICIPATE IN ANY RISK ASSESSMENT ACTIVITIES ASSOCIATED WITH HIS VEHICLE.
  - EXERCISE VETO POWER IN THE PROCESS CYCLE IF ALL PRIOR ANOMALIES AND INFLIGHT FAILURES HAVE NOT BEEN RESOLVED TO SATISFACTION.

- THE PRESENCE OF THE ENGINEER DIRECTOR AND THE SENIOR ENGINEER WILL ENSURE ENGINEERING INVOLVEMENT IN VEHICLE PLANNING AND SCHEDULE INTEGRATION.
- AN ONGOING EFFORT IS UNDERWAY TO INCREASE SUBSYSTEM ENGINEERING SUPPORT ON THE FLOOR.
- SPC HAS ESTABLISHED 1ST LINE DIRECTOR LEVEL POSITION DESIGNED TO BUFFER SHOP PERSONNEL FROM INTENSE PROGRAMMATIC SCHEDULE PRESSURES. THIS NEW ORGANIZATION IS CALLED OPERATIONS CONTROL. IN THE PAST, THE SCHEDULING ORGANIZATION WAS PART OF THE OPERATIONS ORGANIZATION.

DESIGH MANAGEMENT CONT'D

UNDER THIS REORGANIZATION, THE DESIGN REVIEW PROCESS HAS BEEN SIGNIFICANTLY ENHANCED. DESIGN REVIEWS NOW INCLUDE ENGINEERING, OPERATIONS/USER PERSONNEL, SYSTEM SAFETY, RELIABILITY, AND QUALITY PERSONNEL. ON THOSE DESIGN REVIEWS IMPACTING PAYLOADS, PAYLOAD INTEGRATION PERSONNEL ACTIVELY PARTICIPATES.

A SPECIAL POST 51L ACTIVITY WAS INITIATED FOR THE CONDUCT OF ENVIRONMENTAL EFFECTS ANALYSIS ON MLP/PAD CRITICAL SYSTEMS COMPONENTS. STUDY WAS INITIATED IN JULY 1986, AND IS SCHEDULED FOR PROJECT COMPLETION IN MID-APRIL 1987. ANALYSIS CONSIDERS ALL ENVIRONMENTAL EFFECTS, I.E., WIND, RAIN, TEMPERATURE, LIGHTNING, SALT AIR CORROSION, ETC.. THE EFFECTS OF ENVIRONMENTAL VARIABLES UPON SYSTEMS OPERATIONS HAVE BEEN INCORPORATED IN THE SUPPORT ENGINEERING DESIGN REVIEW PROCESS, AND THESE PARAMETERS WILL BE ADDRESSED IN ALL RETURN-TO-FLIGHT AND SUBSEQUENT MODIFICATIONS DESIGNED BY THE SPC.

ALL CHANGES ARE CLOSELY CONTROLLED BY CONFIGURATIION MANAGEMENT, BOTH ON THE VEHICLE SIDE AS WELL AS FACILITIES/GSE. THE SPC SAFETY DIRECTORATE ESTABLISHED A SAFETY REVIEW BOARD IN JANUARY 1987. THE PURPOSE OF THIS BOARD IS TO REVIEW ALL ESRs AND EVALUATE THEIR POTENTIAL SAFETY/IMPACT. THIS PROCESS ENSURES THAT EVERY PROPOSED ENGINEERING CHANGE RECEIVES AN ADEQUATE SAFETY REVIEW. EACH ESR IS STAMPED WITH ONE OF THE FOLLOWING CATEGORIES:

- NO SAFETY IMPACT
- CATEGORY I SAFETY IMPACT
- CATEGORY II SAFETY IMPACT

A. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS

6. PROBLEM REPORTING AND CORRECTIVE ACTION SYSTEM FOR GROUND SUPPORT EQUIPMENT

RECOMMENDATION:

o FIRST AN EDUCATION PROGRAM SHOULD BE INITIATED SO THAT "ALL HANDS" THE IMPORTANCE OF AN ADEQUATE, TIMELY DATA COLLECTION AND ASSESSMENT SYSTEM FOLLOWED BY AN ORDERLY AND TIMELY DISTRIBUTION SYSTEM. IN THE SPACE STATION PROGRAM THE TMIS (TECHNICAL MANAGEMENT INFORMATION SYSTEM) COULD MOST LIKELY SERVE IN THIS CAPACITY. TO ACHIEVE THE NEAR REAL-TIME EXCHANGE OF INFORMATION WHICH IS REQUIRED BY USERS AT ALL NASA CENTERS AND APPROPRIATE CONTRACTORS, THERE MUST BE COMPATIBLE SOFTWARE AND HARDWARE AT ALL SITES. FUNDING IS A PROBLEM.

PROBLEM REPORTING AND CORRECTIVE ACTION SYSTEM FOR GROUND SUPPORT EQUIPMENT

- NASA PROGRAM-WIDE RESPONSIBILITY. AT KSC, THE DEVELOPMENT OF SPDMS II IS MOVING IN THE RIGHT DIRECTION.
  - SPDMS II (SHUTTLE PROCESSING DATA MANAGEMENT SYSTEM) WILL ESTABLISH A COMMON THREAD FOR ALL DISCIPLINES TO DOCUMENT AND SHARE DATA THAT CAN BE USED IN THE PROBLEM SOLVING SCENARIOS AS WELL AS THE DECISION MAKING PROCESS.

A. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS

7. ACHIEVING ADEQUATE SAFETY LEVELS

RECOMMENDATIONS:

- COMMUNICATIONS MUST BE OPEN, CONTINUOUS AND IN SUFFICIENT DETAIL SO AS TO ENSURE NOTHING REQUIRED TO SAFELY GET THE JOB DONE IS MISSED. REVIEWS BY THEMSELVES, FOR EXAMPLE, ARE NOT ENOUGH. PERSONNEL MUST FEEL THAT THEIR VIEWS ARE WANTED AND THAT THEY WILL RECEIVE OBJECTIVE CONSIDERATION. TELECONS ARE FINE, BUT THEY REQUIRE A CONSCIOUS EFFORT TO ASSURE THAT EVERYONE ON THE NETWORK IS GIVEN THE OPPORTUNITY TO PARTAKE.

- TERMS USED MUST BE FULLY UNDERSTOOD BY ALL THOSE ON THE PROJECT SO NOTHING IS LOST IN POSSIBLE "TRANSLATIONS". UNIFORMITY OF LANGUAGE ACROSS A SOPHISTICATED AND GEOGRAPHICALLY DIVERSE PROGRAM IS MANDATORY.

- THERE ARE TWO MAJOR AND COMPLEMENTARY ACTIVITIES IN THE DEVELOPMENT OF COMPLEX HARDWARE. ONE IS THE PRODUCTION OF THE DESIRED OUTPUT AND THE OTHER THE IDENTIFICATION OF UNCERTAINTIES AND THE ASSESSMENT OF THE ASSOCIATED RISK. THE TWO REQUIRE DIFFERENT MENTAL ATTITUDES. AT THE OPERATING LEVELS RESULTS ARE MOST OBJECTIVE AND COMPLETE IF CARRIED OUT BY DIFFERENT GROUPS SUPPORTING AND COMPLEMENTING EACH OTHER. AT DECISION MAKING, THE AVAILABILITY OF TWO POINTS OF VIEW OF COMPARABLE COMPETENCE, ONE FOCUSED ON PERFORMANCE AND THE OTHER ON RISK, IS LIKELY TO PROVE OF CONSIDERABLE VALUE. IT CAN BE BROADLY SAID THAT THE DESIRE TO COMPLETE A DESIGN MAKES IT DIFFICULT TO BE OBJECTIVE ABOUT WHAT MAY BE WRONG WITH IT.

ACHIEVING ADEQUATE SAFETY LEVELS

- o NASA PROGRAM-WIDE APPLICATION REQUIRED. AT KSC THE FOLLOWING ACTIVITIES ARE CONDUCTED TO ENHANCE COMMUNICATIONS AT ALL LEVELS:
  - ALL HANDS MEETING
  - DIALOGUE PROGRAM
  - SAFETY AND QUALITY BRIEFINGS
  - PRETEST BRIEFINGS
  - DESIGN REVIEWS WHICH INCLUDES ENGINEERING, QUALITY, SAFETY, OPERATIONS AND USER PERSONNEL
  - SAFETY AWARENESS, PROGRAM
  - QUALITY AWARENESS, PROGRAM
- o NASA PROGRAM-WIDE REQUIREMENT
- o NASA PROGRAM-WIDE RESPONSIBILITY
- o TO ENHANCE ACHIEVING ADEQUATE SAFETY LEVELS AT KSC, THE FOLLOWING ACTIVITIES HAVE BEEN IMPLEMENTED:
  - QUALITY ENGINEERING PERSONNEL HAVE BEEN ADDED TO QUALITY STAFF TOO:
    - o REVIEW WADS
    - o ANALYZE PROBLEM DATA FOR TRENDS
    - o INITIATE CORRECTIVE ACTION
    - o PROVIDE DEDICATED QE SUPPORT AT THE LCC AND PADS

ACHIEVING ADEQUATE SAFETY LEVELS CONT'D

- FORTY-ONE QUALITY CONTROL INSPECTORS HAVE BEEN RECALLED SINCE JANUARY 1987. TEN ADDITIONAL ARE PRESENTLY BEING RECALLED. WITH THE ADDED PERSONNEL, TECHNICIAN TO INSPECTER RATIO WILL BE:
  - OPF 4 : 1
  - PAD A/B 10 : 1
  - SUPPORT OPS 5.4 : 1
- KEY MILESTONE REVIEW (KMR) HAS BEEN IMPLEMENTED AND EFFECTIVELY UTILIZED DURING THE DESTACK OF OV-104
- TREND DATA IS BEING PROVIDED TO SHOPS ON A WEEKLY BASIS
- AN STS QUALITY PANEL HAS BEEN ESTABLISHED

- TWENTY-EIGHT RELIABILITY ENGINEERS HAVE BEEN ADDED TO SRM&QA STAFF
- SIXTEEN SYSTEM SAFETY ENGINEERS HAVE BEEN ADDED
- CERTIFICATION TRAINING HAS BEEN UPGRADED
- I/ERB
- SAFETY REVIEW OF ALL ESRs
- CONDUCT OF LCC SIMULATION TRAINING FOR STS LAUNCH TEAM PERSONNEL TO MAINTAIN READINESS
- JOINT EMERGENCY DRILLS

A. TECHNICAL AND ADMINISTRATIVE MANAGEMENT FUNCTIONS

8. DESIGNATED ENGINEERING/QUALITY REPRESENTATIVES

RECOMMENDATION:

o CONTINUE THIS PROCESS AS CURRENTLY CONSTITUTED. HOWEVER, DURING THE STS "DOWNTIME" PERIOD EVERY EFFORT SHOULD BE MADE TO MAINTAIN THE HIGH LEVEL OF DER ACHIEVED PRIOR TO THE CHALLENGER ACCIDENT. THIS MAY BE DIFFICULT WITH A REDUCTION-IN-FORCE NOW IN PROCESS WITH THE ANTICIPATED INCREASE-IN-FORCE TO COME WITHIN A YEAR'S TIME. PLAN AHEAD!

DESIGNATED ENGINEERING/QUALITY REPRESENTATIVE

o AT KSC, THE DESIGNATED VERIFIER IS UTILIZED TO PERFORM QUALITY INSPECTION FUNCTIONS ON NON-FLIGHT HARDWARE AND NON-CRITICAL GROUND SUPPORT EQUIPMENT. TO INCREASE THE EFFICIENCY AND EFFECTIVENESS OF THE DESIGNATED VERIFIER PROGRAM, AN ACTION PLAN WAS DEVELOPED WITH THE FOLLOWING AREAS OF INTEREST:

  - A REVIEW OF DESIGNATED VERIFIER CANDIDATES AGAINST THE REQUIREMENTS OUTLINED IN SPI QA-011 (3) KV IS CURRENTLY IN PROGRESS
  - QUANTITY OF DESIGNATED VERFIERS WILL BE EVALUATED AGAINST CURRENT AND REDUCE WHERE POSSIBLE
  - A FORMAL DESIGNATED VERIFIER TRAINING COURSE IS BEING DEVELOPED. ECD: MAY 8, 1987
  - TO ENSURE THAT THE QUALITY OF THE DESIGNATED VERIFIER PROGRAM IS MAINTAINED, PERIODIC AUDITS OF THE PROGRAM WILL BE CONDUCTED BY THE SRM&QA AUDIT STAFF

B. GROUND EQUIPMENT AND FACILITIES

1. GENERAL

LESSONS LEARNED:

- GROUND SUPPORT EQUIPMENT AND OTHER GROUND FACILITIES DO NOT DEPEND UPON MINIMIZING WEIGHT AS DOES FLIGHT EQUIPMENT, BUT THE IMPACT OF CUTTING CORNERS CAN BE AS SEVERE AS IN-FLIGHT EQUIPMENT. CAUSES OF SUCH FAILURES AS NOTED ABOVE WERE USUALLY COMBINATIONS OF DESIGN DEFICIENCIES, OPERATING PROCEDURES OMISSIONS, LACK OF AUDITING BY THE APPROPRIATE NASA AND CONTRACTOR ORGANIZATIONS, AND LACK OF PERSONNEL TRAINING. THESE TYPES OF PROBLEMS WILL ALWAYS BE WITH US, BUT THEY CAN BE MINIMIZED.

RECOMMENDATION:

- EACH OF THE LESSONS LEARNED HAS TO BE TREATED BY MANAGEMENT. THE OLD SAYING "PAY ATTENTION TO THE LITTLE THINGS AND THE BIG ONES WILL TAKE CARE OF THEMSELVES" IS APPROPOS. THERE IS NO DESIRE HERE TO GIVE GENERIC RECOMMENDATIONS.

GENERAL

- APPLICATION OF LESSONS LEARNED
- ALL OF THE FAILURES REFERENCED IN THIS FINDING WERE THOROUGHLY INVESTIGATED AND RESOLUTIONS ARE COMPLETED OR IN THE FINAL STAGES
- CURRRENTLY, KSC IS CONDUCTING A REEVALUATION OF STS GROUND SUPPORT EQUIPMENT TO IDENTIFY ALL HAZARDS AND CRITICAL SINGLE FAILURE POINTS. INCLUDED IN THIS REEVALUATION ARE THE FOLLOWING ACTIVITIES:
    - GROUND SUPPORT EQUIPMENT OMRS DEVELOPMENT AND REVIEWS
    - CONDUCT OF FAILURE MODES EFFECTS ANALYSES
    - ESTABLISHMENT OF A CURRENT CRITICAL ITEMS LIST
    - CONDUCT OF APPROPRIATE HAZARD ANALYSES
    - REVIEW AND DEVELOPMENT OF OMIs
    - REVIEW OF GROUND SUPPORT MAINTENANCE REQUIREMENTS AND SCHEDULING

B. GROUND EQUIPMENT AND FACILITIES

2. WELDING

RECOMMENDATION:

- FOR ANY CONTINUING PROBLEM WITH A CONTINUING PROCESS, SUCH AS WELDING, THE TRIED AND TRUE APPROACH OF CONSTANT AUDITING OF THE PERSONNEL CERTIFICATION AND WORK SITE ACTIVITIES IS MANDATORY. MANAGEMENT IS AWARE OF THIS AND THE QUALITY ASSURANCE AGENCY AT EVERY SITE MUST DO ITS OWN JOB AND NOT ASSUME "ALL IS RIGHT WITH THE WELDING".

WELDING

- o THE SPC BEGAN ACTIVELY PURSUING RESOLUTION OF WELDING PROBLEMS IN EARLY 1986. A FORMAL INTERORGANIZATIONAL WELDING TEAM CONSISTING OF MEMBERSHIP FROM SHOP OPERATIONS, QUALITY, OPERATIONS PLANNING, AND ENGINEERING. THE TEAM IS CHAIRED BY SPC ENGINEERING. THE PURPOSE OF THE WELDING TEAM WAS TO INVESTIGATE ROOT CAUSES OF WELDING PROBLEMS AND RECOMMENDED CORRECTIVE/PREVENTATIVE ACTIONS. SOME OF THE SIGNIFICANT ACTIONS OF THE TEAM WERE AS FOLLOWS:
    - GENERATED A TEST/CHECKOUT REQUIREMENTS DOCUMENT SPECIFYING ACCEPTABLE PERFORMANCE PARAMETERS, ROUTINE PREVENTATIVE MAINTENANCE REQUIREMENTS, AND PRE-OPERATIONAL USE REQUIREMENTS
    - EVALUATED WELDING TECHNIQUES AND UPDATED THE WELDING PROCEDURE TO REFLECT RECOMMENDED PROCEDURE/TECHNIQUE CHANGES
    - IDENTIFIED SPECIFIC TECHNICIANS AND QUALITY PERSONNEL TO BE MEMBERS OF THE SPC WELDING TEAMS WHICH WILL PERFORM ALL FUTURE WELDING OPERATIONS
    - INITIAL AND PERIODIC TRAINING REQUIREMENTS FOR THE WELDING TEAMS WERE IDENTIFIED AND CLASSES WERE CONDUCTED
    - SINGLE POINTS OF CONTACT WITHIN TECH OPERATIONS, QUALITY, AND ENGINEERING HAVE BEEN NAMED TO HANDLE ALL FUTURE WELDING PROBLEMS/CONCERNS
- o A SIMILAR ACTIVITY FOR BRAZING OPERATIONS IS IN THE FORMATIVE STAGE AND IS EXPECTED TO BE OPERATIONAL PRIOR TO RETURN-TO-FLIGHT MODIFICATIONS BEING IMPLEMENTED INTO THE ORBITER.

B. GROUND EQUIPMENT AND FACILITIES

3. HOIST SYSTEMS

RECOMMENDATION:

o WITH KNOWN REQUIREMENTS IT SHOULD BE INCUMBENT UPON THE KSC AND VLS USERS TO ELIMINATE AS MANY SINGLE FAILURE POINTS THROUGH VERY EARLY KNOWLEDGE OF REQUIREMENTS AND PROCUREMENT ACTIONS. AS WITH ANY OTHER EQUIPMENT, FMEA'S AND RESULTANT CRITICAL ITEMS SHOULD BE DEFINED, HAZARDS NOTED AND A FINAL RISK ASSESSMENT MADE. THE RISK ASSESSMENT MUST INCLUDE AND BE DEPENDENT UPON IMPACTS TO THE CRITICAL HARDWARE THAT WILL INTERFACE WITH THE HOIST SYSTEMS.

HOIST SYSTEMS

- UNDER THE CURRENT NASA-KSC HAZARD REEVALUATION EXERCISE, RELIABILITY ENGINEERING IS CONDUCTING FAILURE MODES EFFECTS ANALYSES ON ALL CRITICAL GSE. HOIST SYSTEMS ARE INCLUDED IN THESE EVALUATIONS.

- IDENTIFIED CRITICAL SINGLE FAILURE POINTS ARE COORDINATED WITH GROUND SUPPORT ENGINEERING TO ELIMINATE WHERE POSSIBLE. THOSE CSFP THAT ARE CLASSIFIED AS RESIDUAL ARE EVALUATED FROM A RISK ASSESSMENT POINT OF VIEW AND PRESENTED TO THE RISK REVIEW BOARD APPROVAL/ADOPTION.

- SYSTEM ASSURANCE ANALYSES ARE FINALIZED WITH THE RISK ACCEPTANCE RATIONALE INCLUDED AND FORWARDED TO NASA LEVEL III FOR APPROVAL. NASA LEVEL III FORWARDS THOSE SAAs WITH APPROPRIATE WAIVERS TO NASA LEVEL III FOR APPROVAL OR FUTHER TRANSMISSION TO LEVEL I IF APPROPRIATE.

- DOCUMENTED HAZARD ANALYSIS IS AN INTREGAL COMPONENT OF THE SAA OR WAIVER PROCESS.

B. GROUND EQUIPMENT AND FACILITIES

4. PROCEDURES

RECOMMENDATIONS:

- A LIBRARY AND RETRIEVAL SYSTEM SHOULD BE DEVELOPED THAT IS READILY AVAILABLE FOR NASA AND NON-NASA USERS. LESSONS LEARNED SHOULD BE INCLUDED IN TRAINING COURSES AND MADE PART OF ANY SIGNIFICANT CONTRACT IN THE FUTURE. USE OF LESSONS LEARNED AS WELL AS KEEPING A "RUNNING LOG" OF NEW LESSONS REQUIRES CONSTANT SHORING-UP BY VARIOUS MOTIVATIONAL MEANS.

- PRE-DEVELOPED SYSTEMS TO AID MANAGEMENT IN IDENTIFYING PROBLEMS AND DEVELOPING RESOLUTIONS SHOULD BE INSTITUTED AS SOON AS POSSIBLE. SUCH COMPUTERIZED AND MANUAL FEED PROGRAMS MAY ALREADY BE AVAILABLE AND COULD BE ADAPTED TO NASA USE. FOR EXAMPLE, THE FAA USES THE AVIATION SAFETY ANALYSIS SYSTEM WHICH SCANS MAINTENANCE RECORDS TO DETERMINE POTENTIALLY DANGEROUS TRENDS. FURTHER, FIELD AND HANDS-ON PERSONNEL SHOULD BE REQUIRED TO DOCUMENT AND REPORT PERIODICALLY ON THE EFFECTIVENESS OF TROUBLE-SHOOTING PROCEDURES, HAZARD/PROBLEM IDENTIFICATION PROCEDURES, AND MAINTENANCE MANAGEMENT.

- A SINGLE PROGRAM-WIDE IDENTIFICATION OR CONTROL NUMBER FOR CHANGES. THE PRESENT SYSTEM ALLOWS TOO MANY DIFFERENT NUMBERS TO BE APPLIED FOR A SINGLE ORBITER CHANGE.

- PROVIDE A COMPUTER BASE THAT SHOWS THE DISTANCE THAT MUST BE CLEARED FOR HAZARDOUS OPERATIONS, AND THE DATA THAT THESE DISTANCES ARE BASED UPON (PPM LEVELS OF TOXIC MATERIALS OR TNT EQUIVALENT OF PRESSURE VESSELS). LIST ALL THE INCIDENTS/ACCIDENTS DURING HAZARDOUS OPERATIONS THAT VERIFY OR CONTRADICT THE CLEARANCE OF PROTECTIVE EQUIPMENT REQUIREMENTS. THIS IS NOT UNLIKE THE ABOVE MENTIONED LIBRARY AND RETRIEVAL SYSTEM FOR LESSONS LEARNED.

PROCEDURES

- o NASA PROGRAM-WIDE RESPONSIBILITY
- o NASA PROGRAM-WIDE RESPONSIBILITY
- o NASA PROGRAM-WIDE RESPONSIBILITY
- o NASA PROGRAM-WIDE RESPONSIBILITY AT KSC
  - NASA-KSC IS CURRENTLY IN THE PROCESS OF ACQUISITIONING THE MARS SYSTEM. THIS SYSTEM IS DESIGNED TO PROVIDE REAL-TIME CLEARANCE DISTANCES AND CORRIDORS FOR TOXIC VAPOR RELEASES. SYSTEMS WILL BE PART OF THE FIRING ROOM CONFIGURATION FOR REAL-TIME APPLICATIONS BY THE SAFETY CONSOLE OPERATORS.
  - GP1098E IS THE CRITERIA DOCUMENT THAT ESTABLISHES AND DEFINES QUANTITY DISTANCE DATA FOR HAZARDOUS OPERATIONS. CURRENTLY THIS IS A MANUAL DOCUMENT WHICH COULD BE DEVELOPED INTO A COMPUTERIZED SYSTEM.

B. GROUND EQUIPMENT AND FACILITIES

5. INTEGRATED DESIGN AND MODIFICATION CONCERNS

RECOMMENDATIONS:

- WEIGHT AND COST CONSCIOUSNESS WEAKENED THE MOVE TOWARD BUILDING MAINTENABILITY INTO THE ORBITER. MAINTAINABILITY, ON FUTURE PROGRAMS, MUST HAVE ITS PRIORITY UPGRADED. USE OF STANDARD INDUSTRY HARDWARE WHERE POSSIBLE RATHER THAN UNIQUE HARDWARE SINCE UNIQUE HARDWARE LIMITS THE AVAILABILITY OF SPARES AND DRIVES UP THE COST.

- ESSENTIAL FUNCTIONS NEED TO BE COMPLETELY INDEPENDENT OF OTHER FUNCTIONS AND SUB-SYSTEMS (TRUE MAINTAINABILITY/ACCESS) TO REDUCE INTERFACES/INTERACTIONS.

- DESIGN PROTECTIVE (GSE) COVERS FOR EXPOSED WIRING AND TUBING RUNS AT THE TIME THE ORGINAL EQUIPMENT IS DESIGNED.

- MAINTENANCE PROCEDURES SHOULD BE PROGRAMMED INTO A DATA BASE THAT WOULD INCLUDE TROUBLE SHOOTING AND RETEST PROCEDURES FOR ALL SUB-SYSTEMS. DEVELOP STANDARD PROCEDURES ACROSS ALL SUB-SYSTEMS FOR MAINTENANCE AND RETEST.

- PROVIDE A DEFINED MAINTENABILITY DESIGN CRITERIA AT THE INCEPTION OF THE PROGRAM AND A STRONG DESIGN REVIEW BOARD TO MONITOR ADHERENCE TO THESE CRITERIA.

- FUTURE ELECTRONIC/ELECTRIC SYSTEMS SHOULD HAVE CONNECTOR DESIGNS WHICH ELIMINATE BENT PINS AND INCORRECT KEYING. ORBITAL REPLACEMENT UNITS CANNOT AFFORD THE LUXURY OF DOWN-TIME ON THIS RECURRING PROBLEM.

INTEGRATED DESIGN AND MODIFICATION CONCERNS

- ALL RECOMMENDATIONS REQUIRE NASA PROGRAM-WIDE ATTENTION FOR PROPER RESOLUTION.

C. FLIGHT HARDWARE AND SOFTWARE

1. WELDING

RECOMMENDATION:

o CONTINUED SUPPORT IS REQUIRED FOR BOTH NASA AND CONTRACTOR RESEARCH AND DEVELOPMENT OF WELDING METHODOLOGY, WELDING MATERIALS AND TRAINING ASSOCIATED WITH BOTH WELDING AND NDE OPERATIONS. HARDWARE REQUIRING WELDMENTS MUST BE EXAMINED AS EARLY AS POSSIBLE IN THE DESIGN AND DEVELOPMENT PROCESS TO MINIMIZE ADVERSE EFFECTS DURING MANUFACTURING AND FLIGHT USE. SPENDING "UP FRONT" RESOURCES CAN SAVE A GREAT DEAL OF RESOURCES AND TIME DURING DOWNSTREAM ACTIVITIES.

C. FLIGHT HARDWARE AND SOFTWARE

WELDING

- THIS IS A PROGRAM-WIDE ISSUE. A CONCERTED EFFORT IS REQUIRED BY ALL PARTIES TO ADDRESS THE ISSUES INVOLVED IN ADVANCING TECHNOLOGIES IN WELDING.
- THE ACTIONS OUTLINED BY KSC UNDER GROUND SUPPORT EQUIPMENT APPLIES HERE, ALSO.

C. FLIGHT HARDWARE AND SOFTWARE

2. INSTRUMENTATION

RECOMMENDATIONS:

- NASA AND ITS CONTRACTORS SHOULD APPLY ADDITIONAL RESOURCES TO MATCH THE FLIGHT VEHICLE (STS, SPACE STATION, OTHER) REQUIREMENTS WITH THE APPROPRIATE INSTRUMENTATION SYSTEMS. THIS INCLUDES RELIABLE, WELL BUILT SENSORS AND TRANSDUCERS TO MEET THE ENVIRONMENTAL DEMANDS UNDER WHICH THEY MUST WORK. THIS APPLIES PARTICULARLY TO THE SSME'S AND THE ORBITER 102 WHICH IS TO ACT AS AN EXTENDED R&D VEHICLE. THERE ARE MANY OTHER PROGRAMS AND PROJECTS WITHIN NASA'S PURVIEW THAT REQUIRE BETTER INSTRUMENTS AS WELL...

- NASA NEEDS TO HAVE A COORDINATED APPROACH TO:
  - INSTRUMENTATION STANDARDS
  - INSTRUMENTATION DESIGN
  - INSTRUMENTATION LOGISTICS (SPARES, REPAIR, ETC.)

- PERHAPS NASA SHOULD HAVE A "CENTER OF EXCELLENCE" FOR INSTRUMENTATION ... POSSIBLY LARC.

INSTRUMENTATION

- NASA DESIGN CENTERS AND DEVELOPMENT CONTRATOR RESPONSIBILITY
- NASA PROGRAM-WIDE RESPONSIBILITY
- NASA PROGRAM RESPONSIBILITY

C. FLIGHT HARDWARE AND SOFTWARE

3. UNDERSIZED WIRING AND CABLE DESIGN

RECOMMENDATION:

- ANALYSES MUST BE MADE TO ASSURE THAT THE USE OF UNDERSIZED WIRE CAN NOT BE THE CAUSE OF SHORTING AND A POINT OF IGNITION WITHIN THE HARDWARE IN WHICH IT IS USED. DESIGNERS AND SYSTEM SAFETY ENGINEERS SHOULD PAY CLSOE ATTENTION TO THE USE OF SMALLER GAUGE WIRE AND IF NECESSARY THE SPECIFICATIONS FOR REQUIREMENTS DOCUMENTS SHOULD EITHER BE ADHERED TO OR CHANGED. WAIVERS ARE A SAFETY CONERN.

UNDERSIZED WIRING AND CABLE DESIGN

- NASA DESIGN CENTERS AND DEVELOPMENT CONTRACTORS RESPONSIBILITY

C. FLIGHT HARDWARE AND SOFTWARE

4. HARDWARE CONTAMINATION

RECOMMENDATION:

- DESIGNERS, RELIABILITY ENGINEERS AND SAFETY ENGINEERS MUST GIVE SPECIAL ATTENTION TO CRITICAL COMPONENTS WITH VERY CLOSE TOLERANCES, COMPONENTS AND SYSTEMS THAT ARE DIFFICULT TO CLEAN AND INSPECT, AND PROPER PLACEMENT OF FILTERS TO ALLEVIATE THE SPECIAL PROBLEMS CAUSED BY CONTAMINATNTS. THE PRACTICAL SIDE OF HARDWARE OPERATIONS WHICH INCLUDE THE HUMAN SIDE OF THE EQUATION AND HOW THIS CAN AFFECT THE DEGREE OF CONTAMINATES GETTING INTO A CRITICAL SYSTEM. REDUNDANCY WILL NOT INCREASE RELIABILITY OF THE HARDWARE IF THE ABOVE ARE NOT A PART OF THE DESIGN, DEVELOPMENT AND OPERATIONAL ASPECTS OF THE PROGRAM. FLUID FILTERS THEN ARE NOT THE ONLY ANSWER, BUT CLEANLINESS OF THE FINISHED AND OPERATING HARDWARE. AND LAST, BUT NOT LEAST, IT IS BEST TO NOT USE SWISS WATCH TOLERANCES FOR LOCOMOTIVE SIZED HARDWARE.

HARDWARE CONTAMINATION

FLIGHT HARDWARE SYSTEMS DESIGN, ALONG WITH INTERFACING GROUND SUPPORT NEEDS PROGRAM-WIDE ATTENTION RELATING TO THE HARDWARE CONTAMINATION ISSUE. RESEARCH NEEDS TO BE CONDUCTED BY THE DESIGN CENTERS AND DEVELOPMENT CONTRACTORS TO ENSURE THAT HARDWARE CONTAMINATION STANDARDS/SPECIFICATIONS ARE DEVELOPED THAT ARE SENSITIVE TO THE PROBLEMS/CONCERNS OUTLINED IN THIS SET OF FINDINGS.

C. FLIGHT HARDWARE AND SOFTWARE

5. SOFTWARE/COMPUTERS

RECOMMENDATIONS:

- PROCUREMENT OF COMPUTERS AND DEVELOPMENT OF SOFTWARE PROGRAMS SHOULD NOT BE UNDERTAKEN UNTIL:
  - THERE IS A THOROUGH REVIEW OF THE FAILURE HISTORIES OF PRIOR USED COMPUTERS AND SOFTWARE "GLITCHES" TO ENSURE THAT THESE SAME TYPE OF PROBLEMS ARE UNDERSTOOD (ROOT CAUSES) AND THAT THEY ARE NOT INTRODUCED INTO THE NEW-GENERATION COMPUTERS AND SOFTWARE.
  - PERFORM HARDWARE AND SOFTWARE DETAILED DESIGN AS AN INTEGRATED ACTIVITY AT THE EARLIEST OPPORTUNITY.
  - MAINTAIN VERY CLOSE CONTACT BETWEEN NASA AND THE PRIME CONTRACTORS INVOLVED IN THE MAJOR HARDWARE AND SOFTWARE ... INCLUDING SYSTEMS ENGINEERING AND INTEGRATION CONTRACTORS WHERE USED.
  - ASSESS SYSTEM ARCHITECTURE FOR IMPACT ON LIFE CYCLE COSTS AS WELL AS FOR INITIAL DEVELOPMENT COSTS.
  - MANAGEMENT MUST UNDERSTAND THAT WHILE THE CAPABILITIES OF THE COMPUTER APPEAR TO BE LIMITLESS THERE ARE SOME CONSTRAINTS TO THEIR USE: THEY DO NOT SOLVE PROBLEMS THROUGH THE USE OF REASONING, SYSTEMS ARE LIMITED BY THE DATA SUPPLIED BY MAN, AND ARE INCAPABLE OF MANIPULATING THIS DATA IN ANY WAY WHICH IT IS NOT PROGRAMMED TO DO.

SOFTWARE/COMPUTERS

- ALL RECOMMENDATIONS REQUIRE NASA PROGRAM-WIDE ATTENTION

C. FLIGHT HARDWARE AND SOFTWARE

6. PAYLOADS AND UPPER STAGE PROPULSION SYSTEMS

RECOMMENDATION:

- STANDARDIZATION BETWEEN PAYLOADS AND THE GSE, GROUND FACILITIES AND THE FLIGHT SUPPORTING EQUIPMENT SHOULD BE A DESIGN REQUIREMENT FOR NASA AND ITS CUSTOMERS. DURING THE MISSION THE PAYLOADS REQUIRING EVA MUST ALSO BE DESIGNED TO ACCOMMODATE SUCH EVA'S. INSTALLATION OF PAYLOADS INTO THE ORBITER AGAIN SHOULD BE MADE EASIER BY LOOKING INTO RELIABILITY OF KEY COMPONENTS ON BOTH SIDES OF THE INTERFACE SO THAT REPAIRS AND MODIFICATION KITS CAN BE EASILY INSTALLED.

PAYLOADS AND UPPER STAGE PROPULSION SYSTEMS

- NASA PROGRAM-WIDE RESPONSIBILITY

D. SPACE TRANSPORTATION SYSTEM/CENTAUR

AREAS OF CONCERN

- ESTABLISHMENT OF FIRM PROGRAM GOALS
- CONCURRENT DEVELOPMENT
- INTEGRATION PROCESS
- SAFETY PROCESS
- ACQUIRING SPACE QUALIFIED ELECTRONIC PIECE PARTS
- WEIGHT AND PERFORMANCE

SPC SAFETY ACTION LINE

L. B. SPIVEY

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APPENDIX 3

ADDITIONAL WRITTEN QUESTIONS FOR GEN. SLAY - APRIL 29, 1987

1. Your letter to Dr. Fletcher stated "essential to the success of any risk management process is the certain and timely feedback of preflight and postflight system performance..."

   Has NASA explained to your satisfaction how they will prevent flight rate pressures from interfering with this process as time goes on and the number of flights increases?

   General SLAY. NASA has assured us that they will prevent flight rate pressures from interfering with the risk management process. This process and its controls on decisions to launch are now being established. For example, the new System Integrity Assurance Program Plan (SIAP), including its Program Compliance Assurance and Status System (PCASS), will contribute to the new feedback to Shuttle decisions, including the Flight Readiness Review.

2. Would the system for waiving criticality 1 restrictions (i.e., Level 1 managers concerning themselves only with the most serious criticality 1 items) that you have recommended have given the O-ring problem the visibility it required?

   General SLAY. The prioritization system now being implemented per se might not have flagged the O-ring problem to top management, although it certainly should have focussed attention on it. However, the prioritization system plus more stringent reporting and review of anomalous flight events which we recommended - such as the erosion of the O-rings - should definitely highlight the problem. The new System Integrity Assurance Program Plan requires the review of every anomaly as a part of each Flight Readiness Review, and the orderly close-out of the anomaly.

Appendix 4

EXCERPTS FROM

AEROSPACE SAFETY ADVISORY PANEL

ANNUAL REPORT

COVERING CALENDAR YEAR 1986

Issued February 1987

INCLUDES THOSE SECTIONS THAT
RELATE TO THE CHALLENGER ACCIDENT
RECOVERY PROGRAM

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EXECUTIVE SUMMARY

The Challenger accident set in motion a great number of activities directed toward Space Shuttle recovery, the results of which will affect NASA and its contractors for the foreseeable future. The Aerospace Safety Advisory Panel's factfinding and reporting activities were also in support of returning the Space Shuttle to safe flight status in a timely manner.

Given the breadth of Panel findings and recommendations resulting from this year's factfinding work, this report is structured to provide a compact and useable Executive Summary focusing on the most significant areas of interest followed by stand-alone sections covering Space Shuttle management, Shuttle hardware/software systems, Shuttle operations, NASA Safety/Reliability/Quality Assurance, Space Station Program, and aeronautical activities. The majority of the Panel's efforts were directed toward understanding and providing constructive criticism in support of Shuttle Program recovery efforts.

Panel members and consultants were involved in more than 50 individual and group factfinding sessions, congressional hearings, "one-on-one" meetings with NASA senior managers, and were participants in three National Research Council (NRC) independent oversight groups examining the solid rocket motor redesign, flight rate and manifests, and critical items and hazard analyses. Panel information, oral and written, was supplied to the Presidential Commission on the Space Shuttle Challenger Accident and the House Committee on Science and Technology Investigation of the Challenger Accident.

NASA's response to the Panel's last annual report (issued January 1986) is quite detailed. Due to the changes which NASA experienced in 1986, multiple response letters were provided between September 1986 and February 1987 covering first the aeronautical programs, then the Space Station, and last the Space

Shuttle Program. These appear in the Appendices portion of this report along with a status ("open" or "closed") for each specific point covered.

A report summarizing specific and generic lessons learned as a result of the Panel's factfinding activities was issued in November, "Lessons Learned--An Experience Data Base for Space Design, Test and Flight Operations." Copies went to NASA and contractor organizations.

Space Shuttle Management

1. The Panel finds the recent reorganization of Space Shuttle management to be a positive step in recapturing or rebuilding a spirit of mutual respect and trust at all levels. The Panel recommends that: a priority objective of the new management team must be to enforce NASA's management instructions and to define clearly the responsibilities and authority of the NASA centers; a willingness of all NASA centers to pull together, to subordinate parochial interests, and to help each other is absolutely crucial if the Space Shuttle program is to succeed.

2. The Panel finds that NASA and the Congress need to appreciate that the Space Shuttle is a system which remains primarily developmental with some operational characteristics. It is recommended that NASA needs to emphasize the developmental characteristic or it is likely to miss key elements of the Space Transportation System management challenge.

3. The Panel notes that transfer of part of the Space Transportation System (e.g., Orbiter) logistics responsibility from Johnson Space Center (JSC) to Kennedy Space Center (KSC) must be supported with adequate budgets and appropriate authority to: build a sufficient inventory of spare parts, upgrade the Line Replaceable Units (LRU), and develop an effective program to reduce LRU turnaround time.

4. The Panel recommends that those elements of sustaining engineering that are directly related to launch processing should be the responsibility of the launch operations center (KSC) and those elements of sustaining engineering that require detailed knowledge of the design and development history of airborne hardware should remain with the design centers, as NASA now contemplates.

5. The Panel recommends that NASA should achieve consolidation and upgrading of Space Transportation System data/information systems, particularly those related to configuration management and launch procedures.

6. The Panel finds that although top Shuttle Processing Contractor (SPC) and NASA managers are communicating reasonably well, there is a continuing need to communicate even more directly with workers involved in launch processing to assure that there is a clear sense of mission and direction, and to benefit from employee initiatives and suggestions during these crucial months prior to first reflight.

7. The Panel reiterates that NASA and the Shuttle Processing Contractors need to prevent a recurrence of the condition that developed in 1985 where human resources at KSC were excessively stretched due to launch processing workload and schedule pressures (for example, overtime policy).

8. The Panel recommends that NASA top management should address the growing problem of recruiting and retaining talented engineers and managers due to inadequate Federal salaries. This is not just a Space Shuttle problem.

9. The Panel, in an independent review, concurs with the National Research Council (NRC) Panel conclusions on Space Shuttle Flight Rates and Utilization, that is, an upper limit of 8-10 flights per year with a three Orbiter fleet and 11-13 with a

four Orbiter fleet. Further, the Panel recommends that the Space Shuttle be used only where manned missions are deemed mandatory, and expendable launch vehicles should be used for all other missions.

10. NASA and the Congress should no longer expect that "heroic" performance by its workers and its contractors can compensate for funding shortfalls. The sort of heroism that is needed today is the courage to promise no more than can reasonably be expected given the dollars and people available.

Space Shuttle Systems

1. The Panel finds the redesign of the solid rocket booster (SRB) joints is a marked improvement over the original joint design but there may be problems with mating, demating, and reuse. The approach selected entails more risk than one using new forgings that might permit a more sophisticated design but which would delay first Shuttle flight. Since the proof of adequacy of the design depends strongly on satisfactory results from a thorough certification test program, the Panel recommends a truly complete definition of the certification program and that the elements of the certification program must relate to the specific design requirements.

2. The Panel agrees with the decision to test the solid rocket motors in the horizontal position. In line with this a second horizontal-firing test stand is being constructed that will have the capability to apply simulated flight external dynamic loads. Since there is no way to assure that the tests encompass all possible loading conditions and assembly differences, the Panel recommends that the SRBs and the test stand itself be heavily instrumented to assure that flight-type structural and performance data is obtained as part of the certification program.

3. The Panel urges NASA to provide funds to (1) check Orbiter 102 for loads resulting from the latest loads/stress analysis (designated ASKA 6.0), (2) check the other orbiters for ascent and descent loads, (3) update orbiter load indicators and redlines, and (4) prepare appropriate loads/stress summary reports.

4. The Panel urges NASA to have Orbiter 102 undergo a loads test program to calibrate the strain gauges installed so that flight data from these strain gauges may be used with confidence to obtain wing loads in flight.

5. NASA conducted an extensive reexamination of the Space Shuttle Main Engine (SSME) during 1986 to identify any safety issues that might have been overlooked and then to establish and validate an engine configuration for use in the upcoming Shuttle missions. The Panel finds that the changes being made as a rule do not indicate that there will be any significant improvement in "margin to failure." The Panel recommends that the Phase II engines operate at power levels below 104-percent rated thrust, and if possible at no more than 100-percent rated thrust until these engines have accumulated sufficient flight operating time.

6. The Panel recommends that the Space Shuttle Main Engine two-duct Hot Gas Manifold and the large throat combustion chamber be tested and certified as soon as possible.

7. The Panel recommends that NASA and the SSME contractor continue the development of improved methods for actually demonstrating critical operating failure mode margins and the more rigorous risk assessment analytical procedures. It is recommended that, as part of such procedure, the term "failure" be defined as a violation of any of the governing design criteria for a component rather than as an event such as a structural failure or burn-through.

8. Shuttle Orbiter Computers:

a. The Panel findings regarding the use of upgraded computer systems in late 1988 in either the 4/1 (4 new computers plus 1 old computer) or the 5/0 (5 new computers) configuration include the following factors:

(1) The degree of additional safety provided by dissimilar hardware (there already is dissimilar software);

(2) Human factor contributions to risk--part of the safety provided by computer redundancy is achieved through astronaut training and in flight operations and maintenance procedures performed by the astronauts. This risk difference may well be greater than that in item a above.

(3) The impact of the flight schedule on the scope of software testing, or stated conversely, the impact of required software testing (which is larger for the 5/0 configuration) on the flight schedule; and

(4) The additional costs associated with the ~~5/0~~ 4/1 configuration.

b. The Panel recommends that:

(1) In order to provide greater confidence in the new General Purpose Computer (GPC), it is recommended that the new GPC be flown on several flights as the backup computer before being used as the primary system.

(2) NASA should conduct a study of the human factors aspect of risk associated with in-flight operation and maintenance procedures, particularly changes in procedures and configurations resulting from response to

some failure. Included in this should be a preliminary design of the 4/1 procedures and training and an assessment of their impact.

9. The Orbiter landing gear system (including brakes and nosewheel steering) has been a subject of concern to the Panel as noted in its reports since 1981. NASA's response to Recommendation VI of the Presidential Commission's report appears to meet the intent of the Panel's earlier recommendations. The Panel intends to monitor these areas to assure NASA completes its stated action plan.

Space Shuttle Operations

1. The Panel reviews of NASA and contractor launch processing operations included "one-on-one" interviews with technicians and quality control personnel doing the "hands-on" work. These have shown that recent efforts are steadily improving the effectiveness of both NASA and contractor activities at KSC.

2. Space Transportation System logistics have improved but there remain some concerns:

a. The completion of the procurement of necessary spares.

b. Design improvements to Line Replaceable Units (LRUs).

c. Procedures to control hardware cannibalization between vehicles.

d. Establishment of required repair sites for Line Replaceable Units to improve turnaround time.

e. The many activities in support of returning to flight ("recovery"), e.g., hazards reviews, which may require modifications which affect logistics requirements.

3. The Panel recommends that the recommended "Maintenance Safeguards" program being prepared by NASA in response to the Presidential Commission report be documented quickly and its impact evaluated as soon as possible.

Safety, Reliability, Quality Assurance

1. The Panel ~~finds~~ found that three fundamental weaknesses appear evident. First, there has been a lack of in-line responsibility and authority in the Headquarters organization for establishing policy for the safety engineering function throughout NASA. Second, the elements of the safety functions that have been accomplished at various locations did not include responsibility for defining and controlling the validation and certification programs. Third, there is a conscious lack of quantitative approaches to determine failure-mode probabilities for the purposes of defining acceptable margins, and the relative likelihood of resulting system interactive hazards.

2. The Panel recommends that:

a. Within the newly established Safety, Reliability, Maintainability and Quality Assurance (SRM&QA) organization, NASA should develop the operating policy for all NASA SRM&QA and have the authority to ensure implementation. At each Center there should be a NASA Safety Engineering function reporting to the Center Director. This function should be matrixed into the various programs/projects and should be responsible for implementation of safety policies established by the Headquarters organization.

b. NASA continue to independently review all payload components with regard to their individual inherent safety, and should analyze the safety implications of the potential interactions of payloads in the event of a malfunction of any individual one.

Space Station Program

1. The Panel endorses the initiative to simplify the Space Station design and reduce the extent of manned assembly in orbit using extra-vehicular space suits.

2. The Panel suggests that expendable launch vehicles of greater performance than the Shuttle be included in the launch stable inasmuch as such vehicles may emerge from other national programs.

3. The Panel recognizes that "Safe Haven" and "Life Boat" options are under study in the continuing efforts to define the Space Station. The Panel suggests that both concepts may be required to satisfy ultimate safety requirements for Space Station operations.

4. The Panel is concerned that the computer systems being considered for the Space Station may not be taking into consideration evolutionary changes that will inevitably evolve in the industry in the next two decades. The Panel recommends that the system be designed to allow for the replacement of components as new technology develops. A 32-bit architecture and industry standard bus should be mandatory.

5. The Panel reiterates an old theme: Lessons learned from prior programs must be applied and that such documented material is readily available, e.g., Saturn-Apollo, Skylab, Centaur, Space Shuttle.

NASA Aeronautics

1. The Panel recommends that NASA ensure that the level of the Headquarters Flight Operations Management office and those at the Centers have proper recognition and ready access to their top management.

2. The Panel recommends that the Shuttle Flight Simulators (aircraft) program be completed in a timely fashion so that astronaut training will not be hampered.

3. X-Wing/Rotor Systems Research Aircraft (RSRA) incorporates a number of complex analyses, simulator and test efforts. The Panel recommends the Flight Readiness Review be conducted after completing these efforts and that the correlation between them be carefully examined. Included in this are the following:

   a. The raising of the vertical center of gravity of the vehicle by some 18 inches as compared with the standard RSRA vehicle. This is having a pronounced effect on structuring of the flight test program.

   b. Aircraft structural divergency prediction from the tunnel tests.

   c. Refinement of the flutter and divergence analyses.

   d. Results from the powered model tests correlation with predicted downwash interference predicted by analysis.

   e. The definition of the telemetry requirements with emphasis on software requirements for automatic monitoring.

4. The X-29 project with so many new technologies involved is an example of a meticulously conducted flight program taking safety into account throughout.

I. INTRODUCTION

A. Scope and Structure

The Challenger accident, January 28, 1986, set in motion a great number of activities, the results of which will impact NASA and its contractors operations for the foreseeable future. The Aerospace Safety Advisory Panel's factfinding and reporting activities were also directed toward supporting the return of the Space Shuttle to a safe flight status. This year's annual report mirrors this in several ways:

- Our efforts this past year have resulted in the report devoting itself mainly to the Space Shuttle Program, then to the Space Station Program and to Aeronautics.

- Three major subjects make up the Space Shuttle section: management, systems and operations, safety/reliability/quality assurance.

- NASA has responded to our January 1986 annual report in greater detail than before with circumstances dictating three separate letters from the NASA Administrator: first, covering aeronautics and aircraft operations; second, covering pressure suits, Space Station and space debris; and third, covering the Space Transportation System. These are found in the Appendices.

B. Role of the Aerospace Safety Advisory Panel (The "Panel")

The Aerospace Safety Advisory Panel was established in the aftermath of the Apollo Command and Service Module spacecraft fire January 27, 1967, at Kennedy Space Center. Shortly thereafter the Congress enacted legislation which established the Panel as a senior advisory committee to NASA and to the Congress.

The breadth and depth of the Panel's activities have been defined, refined and redefined since its inception. The Panel's charter is to conduct reviews of NASA and its contractors management and programmatic activities with regard to the safe conduct of their operations, and to advise the NASA Administrator and senior management, and the Congress of Panel findings and recommendations for their consideration and for their guidance.

C. Overview of Panel Activites During CY 1986

The Panel has three parallel streams of effort:

- Factfinding activities conducted by Panel personnel covering significant facets of the Space Transportation System, Space Station, and Aeronautics.
- Special tasks in direct support of the Administrator, for instance, support of those actions being taken by NASA to implement the Presidential Commission recommendations, NASA's response to the Congressional report of the House Committee on Science and Technology.
- Independent oversight groups such as the National Research Council "Panel on Technical Evaluation of NASA's Proposed Redesign of Space Shuttle Solid Rocket Boosters." Aerospace Safety Advisory Panel member, Melvin Stone, participates as our representative and independent observer. The NRC "Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization" had Panel member Norman R. Parmet as a member of this group which issued its report in October 1986. The NASA Administrator requested NRC to form a panel "Space Shuttle Criticality Review and Hazard Analysis Audit" to respond to another Presidential Commission recommendation. Aerospace Safety Advisory Panel members Norman R. Parmet and Gerard W. Elverum, Jr. are full time

members.

The Aerospace Safety Advisory Panel factfinding sessions during Calendar Year 1986 numbered 49, and in addition, numerous ones were associated with the above NRC panels. There were a number of sessions before both the U.S. House and Senate.

In a departure from the Panel's normal factfinding, while at KSC in August and December 1986, a six-man team personally interviewed 48 technicians and quality control personnel doing "hands-on" work for the Shuttle Processing Contractors. The results of this are noted in appropriate sections of this annual report.

II. SPACE SHUTTLE MANAGEMENT

A. Background

In recent annual reports, the Panel has expressed concerns and made recommendations relating to management and organization of the Space Shuttle program. In the 1984 annual report, for example, the Panel discussed the heavy launch processing burden associated with each mission. We cautioned NASA management to avoid advertising the Shuttle as being "operational" in the airline sense "when it clearly isn't." We observed that, in the Panel's opinion, such routine operations would not likely be achieved for 5 to 10 years and NASA should focus on improving the Shuttle's reliability, maintainability, safety, and the allowable flight envelope.

Last year we noted some progress in the Shuttle Processing Contractor's (SPC) handling of the burden of preparing the Shuttle for individual missions. But we also pointed out that problems associated with unplanned vehicle modifications, unexpected anomalies, shortage of spare parts, a generally underfunded logistics program, shortage of qualified technicians, heavy paperwork burden, lack of hardware reliability, and internal planning and communication problems would necessarily limit the flight rate for the foreseeable future. We expressed the view that NASA's goal of 18 to 24 flights per year was not within reach at present and that 12 to 15 per year was the most NASA could hope to achieve. The Panel believed that an "operational" Space Shuttle program was still many years in the future.

Many of these same concerns were raised by the Presidential Commission in the aftermath of the Challenger accident and a number of recommendations dealing with organization and management problems were made. Since then, NASA has made resolution of these problems a high priority. The Administrator appointed General Sam Phillips and his team to review NASA's entire organizational structure. Astronaut Robert Crippen led a study of how to improve the Space Shuttle's program management and internal communications. In November 1986 NASA announced an interim office of space flight management structure. This was finalized with an organizational structure with key personnel assignments announced in February 1987.

The Panel's current observations necessarily take into account these continuing efforts by NASA to respond constructively to the Rogers Commission and to build an organization that can sustain the Space Transportation System with safety and reliability into the next century.

B. Organization

In the past the Panel has urged formation of an entity within NASA charged with full responsibility and authority for Space Shuttle operations. We have urged a stronger leadership role by NASA Headquarters in directing and bringing together the work of the NASA centers. Panel members have commented on what appeared to be a lack of discipline in following internal management instructions and a failure by top management to insist that established procedures be followed. As a result, communication breakdowns and confusion over priorities in the overall Space Shuttle program have occurred. In the opinion of Panel members, NASA's characteristic dedication to excellence as a key ingredient in achieving effective management was being subordinated in some cases to concerns over institutional roles and priorities, i.e., "turf." The extent of organizational change required to fix these breakdowns has been a topic of discussion within the Panel. Since the Challenger accident, we have thought a great deal about these problems and have further refined our views.

The Panel emphasizes that in any management structure responsibility and authority must be clearly identified and delegated. During recent years, NASA has not done this adequately and performance has suffered.

Business management systems are generally self-policed or controlled by the net profit figure. This is a sensitive, effective control system for costs but it is not particularly effective or even desirable for other matters such as maximizing system safety. As a result, we conclude that monetary/financial controls are not appropriate for NASA to use as the principal management control system for the Shuttle. In addition, such financial-based controls do not work well in a bureaucratic system such as the Federal Government. Yearly budgets are politically impacted and must be observed, but this constrains the rate at which the work can be accomplished and can limit the scope of a project.

During the years after Apollo, NASA matured into a more traditional bureaucracy with the attendant problems of self-interest and status quo, and the character and motivation of its managers changed in subtle ways. The program was still important, but more and more attention was paid to the means. Turf battles ensued and communications suffered. Management instructions were not followed in a disciplined manner. In view of this reality, we conclude that you cannot solve this problem simply by changing NASA's Shuttle organization. A key ingredient of success at this time must be a return to the program orientation that was responsible for the earlier successes within the NASA management structure.

The task is no less important and not all that different from the earlier task, and in some ways is more crucial because until the Shuttle can be operated effectively, NASA cannot develop its Space Station. We advisedly say "effective," not "routine" operation. It will be a very long time, if ever, before the Shuttle operation is routine.

Findings and Recommendations:

a. The Panel finds the recent reorganization of Space Shuttle management by creating a Space Transportation Systems (STS) Director, reporting to the Associate Administrator for Space Flight, operating out of Headquarters, and supported by a Deputy Director for STS program matters and a Deputy Director for STS operations is a positive step. The Panel recommends that a priority objective of the new management team must be to determine the correctness of NASA's management instructions, to enforce such instructions, and to define clearly the responsibilities and authority of the NASA Centers--principally JSC, MSFC, and KSC--associated with the STS program. A focus on program success, rather than Center dominance, must be achieved. A willingness of all NASA Centers to pull together, to subordinate parochial interests, and to help each other is absolutely crucial if the Space Shuttle program is to succeed.

b. The Panel finds the problem of worker morale, especially at KSC, is of special concern. This is a classic problem of organizational and inspirational leadership that cannot be solved simply by changing institutional structures. The Panel recommends that NASA's top management, including the Administrator, Associate Administrator for Space Flight, the STS Director, and the Center Directors, take the lead in recapturing or rebuilding a spirit of mutual respect and trust at all levels.

c. The Panel notes that recapturing NASA's self-confidence in managing the Shuttle program is crucial to success and requires NASA's leadership to keep in perspective the activities of the many advisory groups, task forces, and panels that have been created in the aftermath of the Challenger accident. NASA has the ultimate responsibility and authority to manage the National Space Transportation System after giving appropriate consideration to the findings and recommendations of oversight groups. The individuals involved in these review panels, as well as Members of Congress, should recognize that excessive reliance by NASA management on external and internal review groups runs the real risk of destroying NASA's initiative and self-confidence, key elements of success in any human endeavor.

C. Research and Development vs. Operational Status

In 1984, the Panel noted in its annual report that ". . . continuing use of the term 'operational' simply compounds the unique management challenge of guiding the STS through this period of 'developmental evolution.'" The Panel stressed the importance of upgrading the safety and reliability of many of the Space Shuttle's critical systems (e.g., SSME, orbiter structure, avionics, and brakes) and of recognizing that this continuing process of change and improvement would require the discipline and caution of a developmental, as opposed to "operational," program. In the aftermath of the Challenger accident, and taking into account the extensive redesigns and investigations underway, the developmental character of the STS is now clearly accepted by NASA and its contractors. It is still the Panel's view that the Space Shuttle is not likely to achieve operational status in the airline sense.

At the same time, however, NASA must guard against an exaggerated response to this renewed focus on Space Shuttle development. There are activities associated with launch processing, in particular, where achievement of more routine and predictable operations would enhance safety and reliability. For example, a proliferation of data systems still exists with roughly two dozen containing Shuttle data. This complicates development of centralized management information around which a more coherent operation--communication, scheduling, goals, performance, motivation, human resources--can be developed by the Shuttle Processing Contractor.

Findings and Recommendations:

a. NASA needs to recognize that the Space Shuttle is a system with both developmental and operational characteristics. To emphasize either characteristic at the expense of the other is likely to miss key elements of the space shuttle management challenge.

b. Transfer of a part of the Space Transportation System (Orbiter) logistics responsibility from JSC to KSC must be supported with adequate budgets to build a sufficient inventory of spare parts and an upgrading of Line Replaceable Units (LRUs), linked to a capability for timely refurbishment, to eliminate cannibalization of parts from other orbiters and to support orderly launch processing operations.

c. Based on the Panel's reviews of the launch processing activities at KSC, particularly flight critical items, the Panel recommends that those elements of sustaining engineering that are directly related to launch processing should be the responsibility of the launch operations center (KSC). These include the evaluation of launch base test data, generation and maintenance of test and launch procedures, logistics engineering, quick-look launch phase flight data analyses, design changes to GSE and launch facilities, and troubleshooting of hardware. Elements of sustaining engineering that require detailed knowledge of the design and development history of airborne hardware should remain with the design centers and their contractors as NASA now contemplates.

d. NASA, in collaboration with the Shuttle Processing Contractor, should make a concerted push to achieve greater consolidation and upgrading of STS information systems, particularly those related to configuration management and launch procedures. For example, the Problem Reporting and Corrective Action System (PRACA) is not programmed to identify big problems and trends in a timely manner. An improvement in management information will contribute directly to more reliable and predictable launch processing.

D. Human Resources

As with most undertakings, the quality of NASA's human resources in managing the Space Shuttle program will be the single most important factor in determining its ultimate success or failure. Specifically, in view of the opportunity for and potential consequences of human error in Space Shuttle processing, management of employees at KSC by the Shuttle Processing Contractor (SPC) and NASA is of particular concern to the Panel. It would appear that these human resources were stretched excessively prior to the Challenger accident.

It has been reported to the Panel that in August 1985--with SPC employment at 6,100--the overtime rate at KSC was running 10 to 15 percent, with much higher rates in certain critical areas, such as the Orbiter Processing Facility, Pad, Launch Control Center, and Facility Operations and Management. To accommodate the acknowledged schedule pressures, the SPC and NASA were forced to rely on extreme efforts by many key workers, regardless of personal considerations. Workers have told the Panel of considerable internal pressures to work heavy overtime schedules. The Panel has found no evidence of a "safety valve" to balance pressures on the KSC workforce with pressures to maintain a launch schedule. Once the flight rate picks up, the Panel is concerned that reliance on the human endurance of SPC and NASA personnel at KSC may again become excessive.

NASA shares the problem of inadequate salary levels with many other Federal agencies. A program of the technical and management challenges of the Space Shuttle requires the best talent in the Nation if safe and efficient operations are to be achieved. Increasingly, the best often will not work for the salaries that the Federal Government can offer. This fact was clearly confirmed by the recent recommendations of the

Quadrennial Commission on Federal Pay that sought to reduce the 40-percent erosion in top management salaries that has occurred since 1969. Increases as high as 80 percent were proposed by the Quadrennial Commission. The President, however, proposed much smaller increases in the 2-4 percent range that will do little, if anything, to close the salary gap. At this writing it is not known what action, if any, Congress will take in response to the President's recommendations.

As a consequence of this apparent failure to solve the salary problem, NASA, along with many other Federal agencies, will continue to lose key senior managers and will find it difficult to recruit and retain senior personnel from among "the best." This steady erosion of management and engineering talent will make it increasingly difficult for NASA to operate the Space Shuttle in a safe and efficient manner.

Findings and Recommendations:

a. The Panel finds that recent layoffs by the Shuttle Processing Contractor of a large number of workers at KSC to accommodate the STS standdown have lost skilled employees who will be needed in 1987 as preparations intensify for a resumption of Space Shuttle launches. The Panel recommends that the Shuttle Processing Contractor should identify these losses and begin now locating, recruiting, training and retraining the necessary persons with the skills to support all aspects of these preparations, including modifications to the Orbiter and other STS systems that will be identified by ongoing NASA reviews.

b. The Panel finds that uncertainty among Shuttle Processing Contractor workers at KSC as to job security has undermined morale and other management efforts to improve communication and worker participation in launch processing decisions. It is recommended that top Shuttle Processing Contractor and NASA management should personally act to eliminate this uncertainty by dispelling rumors when they arise and leveling with workers as to their future job prospects.

c. The Shuttle Processing Contractor is expanding training opportunities for workers but often this training is not focused on meeting the needs of individual workers. Training opportunities need to be linked more explicitly to expanding worker skills to permit longer term career progression.

d. The Panel finds there still appears to be some difficulties in communication between top Shuttle Processing Contractor and NASA managers with floor supervisors and workers. The paperwork burden remains heavy. Instructions regarding specific processing operations are often inaccurate or incomplete, leading to inefficient scheduling and potentially to safety problems. It is recommended that top managers need to communicate more directly with workers involved in launch processing to provide a clear sense of mission and direction, as well as to benefit from employee initiatives and suggestions.

e. NASA and the Shuttle Processing Contractor need to create a system/procedure that will prevent a recurrence of the condition that developed in 1985 where human resources at KSC were excessively stretched due to schedule pressures.

f. NASA top management should document the growing problem of recruiting and retaining talented engineers and managers due to inadequate Federal salaries. The Panel stands ready to review these data and make appropriate recommendations to the Office of Management and Budget and the Congress.

E. Schedule vs. Budget

Panel members have believed for some time that the Space Shuttle program has been underfunded and that these shortfalls, in turn, contributed to a Space Transportation System that was incapable of meeting the launch schedule NASA projected prior to the Challenger accident. The present review of Failure Modes and Effects Analysis (FMEAs) and Critical Items List (CILs) will likely generate a number of modifications to the Space Transportation System that will have to be accomplished prior to resuming a flight schedule. It is essential that budgetary concerns not unduly limit the designs and modifications that are needed from a safety and reliability perspective. If funds are not available to accomplish this work due to budgetary ceilings or other fiscal limits, the only acceptable alternative is to stretch out the schedule.

Findings and Recommendations:

a. The Panel, in an independent review, concurs with the National Research Council Panel conclusions on Space Shuttle Flight Rates and Utilization, i.e., an upper limit of 8-10 flights per year with a three orbiter fleet and 11-13 with a four orbiter fleet. These projections are based on a number of optimistic assumptions that involve adequate funding resources and the absence of any new major development problems. If these assumptions are not borne out, the flight rates must be reduced.

b. NASA should no longer expect that "heroic" performance by its workers and its contractors can compensate for funding shortfalls. What is needed today is the courage to promise no more than can reasonably be expected given the dollars and people available.

III. SPACE SHUTTLE SYSTEMS

The Panel has continued its process of reviewing all elements of the Space Shuttle systems and operations. Since the Challenger accident, all these systems have been the subject of reviews by both internal NASA and external groups. The objective of this process is to enhance the safety of flight by discovering weaknesses in design or operation that may have lingered or not been discovered and to devise and implement appropriate corrective action. The Panel is participating in these efforts in a variety of ways. These include having individual members serve on several of the oversight committees of the NRC such as the Solid Rocket Booster Redesign panel and by factfinding meetings with the contractor organizations and NASA Centers responsible for elements of the Space Shuttle.

In the following sections the results of these activities are described and recommendations are provided.

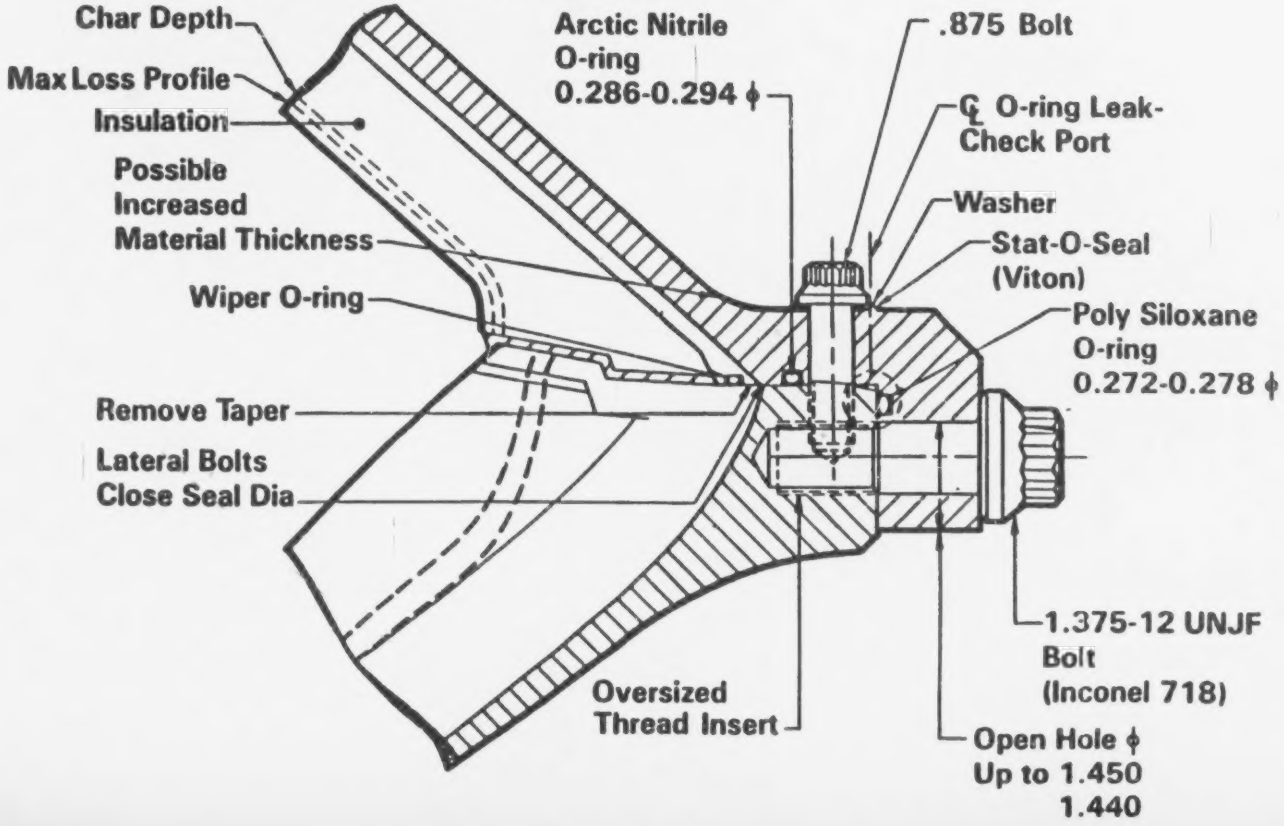
A. Solid Rocket Booster (SRB)

A representative of the Panel is participating in the meetings of the National Research Council (NRC) Panel on SRB Redesign. The following observations are made, based on the information provided at these meetings and additional information brought to the attention of the Aerospace Safety Advisory Panel.

Field Joints: NASA has decided to proceed with a redesign effort for the field joints that make use of 72 existing steel case forgings. This approach entails more risk of not achieving design objectives than would a more sophisticated approach that would offer the possibility of a higher margin of safety. Such an alternate design would, however, require new forgings and would cause a delay of 3 to 5 years in the resumption of Shuttle flights. Such a prolonged delay could result in a loss of national support for the space program. Also, the delay could

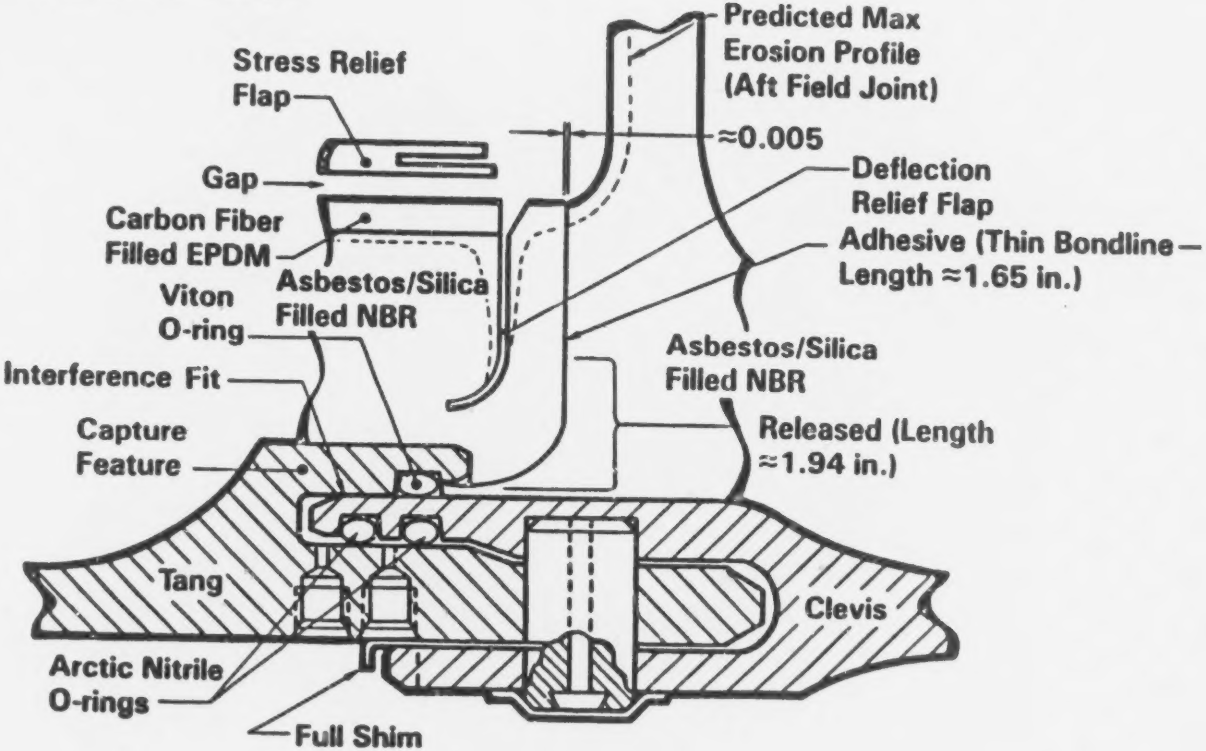
SRM NOZZLE RECOVERY REDESIGN

Case-to-Nozzle Baseline Joint Configuration

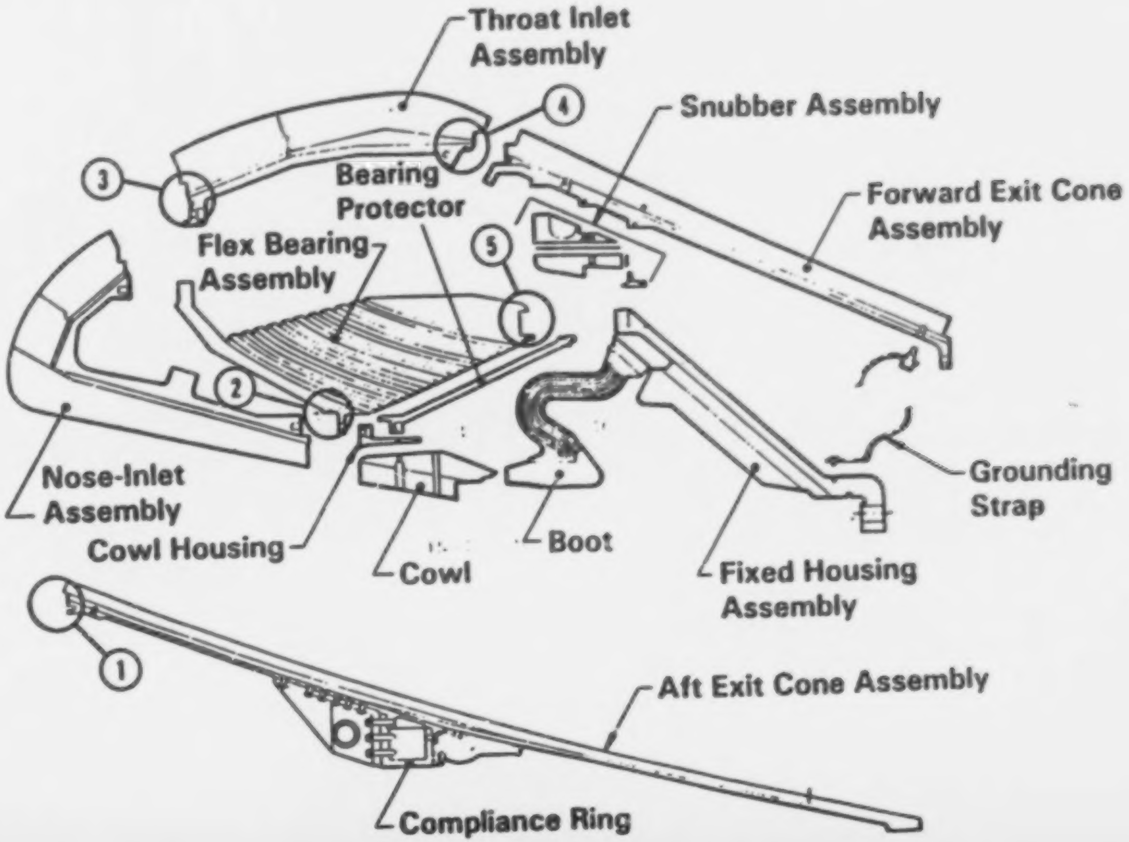

Char Depth
Max Loss Profile
Insulation
Possible Increased Material Thickness
Wiper O-ring
Remove Taper
Lateral Bolts Close Seal Dia
Arctic Nitrile O-ring 0.286-0.294 ϕ
.875 Bolt
℄ O-ring Leak-Check Port
Washer
Stat-O-Seal (Viton)
Poly Siloxane O-ring 0.272-0.278 ϕ
1.375-12 UNJF Bolt (Inconel 718)
Oversized Thread Insert
Open Hole ϕ Up to 1.450 1.440

CASE FIELD JOINT

Field Joint Baseline Design


Stress Relief Flap
Gap
Carbon Fiber Filled EPDM
Asbestos/Silica Filled NBR
Viton O-ring
Interference Fit
Capture Feature
Tang
Arctic Nitrile O-rings
Full Shim
Predicted Max Erosion Profile (Aft Field Joint)
≈0.005
Deflection Relief Flap
Adhesive (Thin Bondline—Length ≈1.65 in.)
Asbestos/Silica Filled NBR
Released (Length ≈1.94 in.)
Clevis

SRM NOZZLE RECOVERY REDESIGN


Throat Inlet Assembly
Snubber Assembly
Forward Exit Cone Assembly
Bearing Protector
Flex Bearing Assembly
Nose-Inlet Assembly
Cowl Housing
Cowl
Boot
Fixed Housing Assembly
Grounding Strap
Aft Exit Cone Assembly
Compliance Ring
①
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place the United States further behind foreign competition in manned space flight.

Case to Case Joint: The baseline field joint redesign chosen includes an interference-fit capture feature to minimize gap opening that results from joint rotation; three "O"-ring seals with two intervening test ports; improved unvented (bonded) insulation joint configuration to prevent hot gases from reaching the seals; larger seal gland widths to allow axial movement; and a joint heater to control temperature at the seals. Seal materials with improved resiliency and grease compatibility may eliminate the need for joint heaters.

In the baseline design, the unvented insulation at the segment juncture is bonded together. This sealed insulation may be subject to local vent holes which can make it difficult to test under the "worst-case-leak" condition. In addition, it would be difficult to disassemble the segments without damage to the insulation at the joints. The alternate "vented" labyrinth design for this interface between segment insulation has been eliminated due to problems surfaced during thermal calculations. Additional unvented designs with various bonded insulation joints are being pursued.

These configurations will be tested in sub-scale and full-scale hot-firing tests.

Tests have been successfully performed on removable composite ring overwraps with aluminum wedges and tensioning bolts on the existing steel cases adjacent to the field joints. This concept is being fully evaluated as to its effectiveness in reducing field joint rotation in the Engineering Test Motor (ETM) static test using four existing steel case segments.

In addition to the designs just described, NASA is pursuing other field joint redesigns (block II) that may enhance the safety of the SRB for the long term.

Nozzle-to-Case Joint: The redesign of this joint incorporates 100 radial bolts, each with a "Stat-O-Seal" under its head. The bolts are intended to reduce the relative motion between the housing and the aft dome. The new design also includes a third (wiper) seal and a second test port as well as circumferential flow baffles in the insulation.

The addition of the bolts adds multiple potential leak paths and residual stresses in the fixed housing that can reduce the reliability of the joint. The wiper seal bears on insulation rather than on metal. This could limit the pressure that can be employed during leak testing of the assembly.

There are a number of unresolved design questions at this time. Among them are the possibility of hot gas jet impingement or circumferential flow of such gas that could result from an insulation debond, and the ability to disassemble the nozzle from the case without damage to the insulation. Two alternate designs are being considered. One incorporates a metal thermaloc U-seal which maintains contact with the nozzle fixed housing and case aft dome during pressurization. The other concept is to insulate over the case-to-nozzle joint making it a factory joint. This design requires a new "field type" joint in the aft segment case and a redesign of the aft propellant grain. Other contractors have proposed a design wherein joint rotation acts to close the joint against the seal but, unfortunately, this approach probably requires a new forging with attendant schedule impact.

Nozzle System: The existing nozzle seals have performed adequately to date. The new design requirement for redundant and verifiable seals has, however, resulted in a complete redesign of all these seals. All such nozzle internal joints (there are five) are being revised to contain two seals with an intervening seal test port. All of these joints act to close the joint under operating load conditions except for the "number 5" joint which acts to close the inboard seal and open the outboard seal in operation.

In addition to internal nozzle joint seal design changes, the ply lay-up angles of the ablator material on the several rings of the nozzle structure are being changed to reduce, if not eliminate, the pocketing erosion that has been experienced in the past. The cure cycle for the graphite composite material employed may have to be changed in order to limit erosion and charring.

The changes being made are many and complex and to validate their suitability requires full-scale, full-duration, hot-firing tests. The number of such tests required to establish confidence in the reliability of these changes will be large and is yet to be established.

Thus, the categorical application of the requirement that all seals be redundant and verifiable to all SRB joints may affect cost, schedule, and inspection procedures and may also reduce inherent reliability.

Igniter System: The thickness of the igniter aft dome case will be increased to eliminate a negative margin of safety. This redesign is the only change that has been deemed mandatory for first reflight by NASA.

In the past, the igniter joint has exhibited primary seal erosion and blow-by during the full-scale hot-firings. Test should be made to identify the joint leak paths so corrective action can be taken.

Verification of Insulation Bondline Integrity: Major improvements in inspection techniques and procedures are required in order to be able to verify the integrity of the insulation bondline with confidence. The use of new non-destructive evaluation techniques (NDE) to detect a defective bond between insulation and case before propellant casting and prior to final stacking of the segments must be pursued aggressively.

General: The Panel is of the opinion that the redesigned joint is an improvement over the original and can result in a safe structure. Mating, demating, and re-use of the baseline configuration may prove to be a problem, however. Proof of the suitability of the redesign depends critically on achieving satisfactory results from a thorough, carefully planned, conducted, and instrumented test program. At present there is not sufficient definition of the development and certification test programs to permit comment as to their adequacy.

Achieving higher safety margins than that possible with the current baseline configuration would likely require something like the "Langley" design (or its equivalent) for the field joints and the "Hercules" design (or its equivalent) for the nozzle-to-case joint wherein the segment joints tend to close as the motor builds up internal pressure.

Horizontal vs. Vertical Firing Tests: In its report, the Presidential Commission on the Challenger Accident recommended that SRB motor firings to certify the redesign duplicate expected flight conditions as closely as possible and that conducting such firings with the SRB in a vertical attitude be given thorough consideration. The testing planned to verify the corrective action taken to remedy the problem encountered by the Titan 34D solid motor will be conducted in a vertical firing attitude using existing Titan test facilities.

NASA has given thorough consideration to the pros and cons of horizontal and vertical firing attitudes. The Panel concurs with NASA that peak loads that simulate extreme conditions on the joints can be applied to the SRB during horizontal attitude test firings. It is extremely difficult, if not impossible, to simulate such loads during vertical attitude test firings. Other parts of the SRB are not sensitive to firing attitude or are unchanged and have demonstrated their flightworthiness during the 24 successful Shuttle flights. Opting for vertical testing of the SRB would entail large added costs and an additional months of schedule time.

The Transient Pressure Test Article (TPTA) provides the means to test the insulation joint seals and the capture feature over a broad range of temperatures, dynamic conditions, and ignition times, repeatedly.

The addition of a second horizontal firing test stand to the program not only adds test capacity, it includes equipment that enables the simulation of flight-type external dynamic loads. This will enhance the validity of the test program results.

It is the opinion of many experts in solid rocket motor design that the number of tests in the preliminary test program is minimal for the scope of the redesign. The Panel notes that it recognizes that there is no way to guarantee that any number of tests can ensure that all possible operating and loading conditions and assembly differences can be encompassed by a finite test program.

Findings and Recommendations

1. SRB Joint Redesigns

The Panel finds that NASA is proceeding with a redesign of the SRB joints that use existing steel cases and forgings. The redesign is a marked improvement over the original joint design but may have a problem with mating, demating, and re-use. The approach selected entails more risk of not being able to achieve design objectives than would one using new forgings that might permit a more sophisticated design but which would delay the first Shuttle flight for 3 to 5 years. Proof of adequacy of the redesign depends strongly on satisfactory results from a thorough test program. The Panel agrees that the baseline case field joint and nozzle-to-case joint redesigns (and their parallel and alternate designs) along with a thorough and rigorous qualification test program can result in a safe structure.

The Panel recommends that a more complete definition of the certification test program be required in order to determine its adequacy. The Panel also recommends that a concerted effort be made to include additional full-scale hot-firing tests in the final test program plan so as to reduce the possibility of undiscovered weaknesses. Further that during the first year of resumed Shuttle flights, the SRBs be heavily instrumented to obtain both structural and performance data and that these data be considered as part of the certification program.

To attain a SRB design with a higher margin of safety for the long-term use with the Shuttle, it is suggested that NASA proceed with the development of the "Langley" design (or its equivalent) for the case field joint and the "Hercules" design (or its equivalent) for the nozzle-to-case joint in an aggressive effort.

2. SRB Test Firing Attitude

The Panel agrees that to check the redesigned SRB joints, peak test loads that simulate extreme conditions can be applied to the SRB when it is in the horizontal attitude. It is extremely difficult to simulate such loading with the SRB in the vertical attitude.

A second horizontal-firing test stand is being added to the program. This added test stand will have the capability for the application of external dynamic loads. It will, of course, also permit an increased rate of testing.

The Panel recommends and agrees with the decision to conduct the hot-firing tests of the SRB in the horizontal attitude. The Panel notes that, despite the array of sub-scale, large diameter, and full-scale tests contemplated, there is no way to ensure that the tests encompass all possible loading conditions and assembly differences. The Panel strongly urges, therefore, that during the first year of resumed STS flights, the SRBs be heavily instrumented to obtain structural and performance data and that these data be considered to be part of the certification program.

B. Orbiter Structural Loads

The current loads/stress analysis cycle (designated ASKA 6.0) will provide analyses of the structure of Orbiters OV-103 and OV-104 and this will be finished by February 1988. There are not sufficient funds in the program budget to provide such an analysis for Orbiter OV-102. This would leave this vehicle with a different basis for the definition of structural capability than the others in the fleet. In addition, funds are not available to provide separate ascent and descent load information or for the updating of pertinent load indicators (strain gauge and redlines) or for the preparation of summary strength and loads/stress reports. The technical community agrees that these tasks should be accomplished.

Because the Space Shuttle will be used at least until the beginning of the next century, there will undoubtedly be a need from time to time to refurbish the vehicles, expand the operating flight envelope, and answer questions regarding the structural adequacy of the vehicles under new conditions. Without the data base provided by the analyses and reports noted above, evaluations like those mentioned cannot be made in a timely manner.

Findings and Recommendations - Orbiter Structural Loads

The Panel finds that no funds have been provided to check Orbiter 102 for the loads/stress analysis (ASKA 6.0) or to check all vehicles for separate ascent and descent loads, update load indicators and redlines, and for the preparations of summary loads/stress and strength reports.

The Panel recommends that NASA provide funding to accomplish these tasks as the information developed is required for decision-making and should be readily available. These tasks should be performed as soon as the loads/stress analyses (ASKA 6.0) are completed.

C. Experimental Verification of Orbiter Flight Loads

For the Space Transportation System flight in early 1986, Orbiter 102 was instrumented with approximately 250 pressure transducers on both upper and lower wing surfaces as well as with a number of strain gauges on the wing structure. This instrumentation was provided to obtain experimental data under flight conditions that would permit the verification of the structural load/stress analyses. It was determined that the pressure transducers read incorrectly (low) because of the roughness of the surface in the vicinity of the islands in the insulating tiles containing the instruments. The pressure transducers are, therefore, not suitable for use in determining wing loads in flight in their present installation. Wind tunnel testing and experimentation with installation techniques are required to determine whether techniques can be devised that will permit pressure data to be used for reliable determination of wing loads in flight.

Until it becomes possible to use pressure data with confidence, verification of analytical loads must rely on data from strain gauges. It is estimated that data derived from at least four flights will be required to correlate strain gauge derived information with the ASKA 6.0 loads/stress analyses. In order to do this with a sufficiently high confidence, Orbiter-102 should undergo a loads calibration test program while the fleet is grounded so that the strain gauges can be accurately calibrated, the instrumentation system "wrung out", and answers to questions regarding the number of gauges employed answered.

Findings and Recommendations - Experimental Verification of Orbiter Flight Loads

The Panel found that data from the pressure gauges installed on vehicle Orbiter-102 cannot be relied upon for predicting wing loads accurately, and therefore data from the installed strain gauges will have to be used to verify the ASKA 6.0 loads/stress analyses. The strain gauges installed on the vehicle have never been calibrated as installed.

The Panel recommends that Orbiter-102 undergo a loads test program to calibrate the strain gauges installed so that flight data from these strain gauges may be used with confidence to obtain wing loads in flight. This testing should be accomplished during the present hiatus in STS flights.

D. Space Shuttle Main Engine (SSME)

As reported in prior years, a multiphase program has been underway to improve the operating margins and/or the time between replacement for many of the critical engine components. This program had focused its resources primarily on what was designated as the Phase II part of the program. The work consisted of specific improvements in various turbo-machinery components and their incorporation into two Phase II engines to be "certified" for operation at 109 percent of rated thrust. One of these engines had completed its certification testing in 1985 and the second engine was in test before the STS 51-L accident.

Following its review of 51-L, the Presidential Commission recommended that NASA reassess its critical items and hazard analyses to ensure that all Criticality 1 items were properly identified and that actions were taken to minimize their risk. This review was initiated throughout NASA and its contractors in March 1986. The NASA strategy for safely returning the Shuttle to flight status included the following:

- All waivers on Criticality 1 and 1R items be revalidated and submitted for new approvals.
- All items for which an acceptable revalidation and waiver could not be justified using more stringent guidelines for adequacy of the retention rationale were to be redesigned and certified for flight.

In response to this NASA direction, a major program was undertaken on the SSME. This program encompassed a number of different areas of effort which, when completed, would provide a basis for defining a modified engine configuration having better margins of safety and an improved validation test program. In addition, a more sophisticated risk assessment methodology would provide criteria for operational constraints which would govern use of modified engines in the return-to-flight program. These constraints might encompass power limitations of only 100 percent of rated power on the first few flights as it might not be possible to provide engines of full margin configuration until a year or two after first flight.

This program was reviewed in considerable detail by propulsion specialist members of the Panel in May, June, October, and November of 1986. The primary elements of the program are listed below.

Element 1: Establishment of a modified engine configuration based on the Phase II certification program and conversion of

Phase I to Phase II engines prior to their next flight use. The new engine configuration must incorporate a number of additional changes to the current Phase II configuration that are necessary to resolve many issues currently identified.

Element 2: A thorough re-do of the Failure Modes and Effect Analysis (FMEAs) and Hazard Analyses and Criticality categorizations of identified failure modes for the Phase II engines. This re-do was carried out by Rocketdyne (the engine contractor) and, separately, by an independent contractor, the Martin-Marietta Company.

Element 3: A thorough review of the Interface Control Documents between the engine and the Orbiter and external tank.

Element 4: A review of all discrepancy reports on the "fleet leader" engines and turbo-machinery and the re-establishment of the engine redline rationale and the launch-commit criteria.

Element 5: A revalidation of the KSC Operating and Maintenance Instructions based on the Phase II engine design and operating constraints, the changes arising from the 51-L reviews, incorporation of all pertinent "unwritten" limits in prior use, and the elimination of prior exceptions and waivers by making the required changes.

Element 6: A review of the Flight Readiness Review and Countdown Decision Making processes with recommendations for improvement to be provided to NASA.

Summary and Assessment of the Program

The engine configuration to be incorporated in the next series of Shuttle flights will be based on the Phase II engines which were being certified for 109-percent of rated thrust. These Phase II engines will incorporate new turbopump component designs developed during the Phase II improvement program carried out in 1984 to 1986. During the course of the Phase II effort, several additional engine hardware issues surfaced that also required resolution. The resulting design modifications will also be incorporated. In addition to such hardware issues that arose from the ongoing engine test program, the 51-L accident led to considerable rethinking of such issues as redlines, instrumentation, and operational constraints. Also, the results of the re-do of FMEA/CIL and hazard analyses in this program identified a number of areas wherein the effect of a given failure mode might be reduced or eliminated by changes in hardware, redlines, software, or inspection procedures. Therefore, the new engine configuration must account for all of these issues in a way that will result in high confidence that Shuttle flights can be resumed safely.

The several issues may be put in the following categories:

1. Those that require changes regardless of the operating flight power level.
2. Those that require additional changes for operation at 104-percent maximum.
3. Those that require additional changes for operation at 109-percent maximum.

In all three categories, acceptable solutions may be either hardware design changes or other techniques such as a new redline, life limit, or inspection procedure. In addition to those changes that are considered mandatory prior to the next flight regardless of thrust level or flight profile, a number of items have been identified that effect additional improvements in margins of safety at given thrust levels or enhanced life cycle limits and, hence, cost effectiveness for LRUs. Some of these changes are under development (albeit very slowly) in the so-called Phase II+ and Precursor programs about which we reported in previous years.

In a session at Rocketdyne in November 1986, the changes required for the next flight were reviewed. As of that date, there were 25 items identified that require resolution and changes to either hardware or operating limits. These items are listed in Table I. Of those listed, the Panel reviewed those marked with an asterisk (*) in considerable depth as they concern the most significant issues to be resolved before the next flight irrespective of the thrust level selected. They can be grouped as follows:

1. High Pressure Turbopump Blade Cracks
2. Bearing Ball Temperatures in the Oxidizer Pumps
3. High Pressure Fuel Turbopump Coolant Liner Buckling

TABLE I

NEXT-FLIGHT CHANGES IN ADDITION TO PHASE II

1. 1st Stage High Pressure Fuel Turbopump (HPFTP) Turbine Lobe Cracks*
2. 2nd Stage HPFTP Turbine Face Cracks*
3. HPFTP Coolant Liner Maximum Pressure*
4. HPFTP 1st Stage Impeller Hub Cracks
5. 1st Stage High Pressure Oxygen Turbopump (HPOTP) Turbine Shank Cracks*
6. HPOTP Bearing Ball Temperature*
7. Low Pressure Oxygen Turbopump (LPOTP) Bearing Ball Temperature*
8. Main Combustion Chamber (MCC) Outlet Neck - Electro-Deposited Nickel (EDNi)*
9. Main Injector Liquid Oxygen Inlet Seam Weld Defects
10. Nozzle Steerhorn Weld Life
11. 4000 Hz Gimbal Bearing Accelerometer Vibration*
12. Fuel Preburner Diffuser Crack
13. Low Pressure Fuel Duct Buckling
14. MCC Liner Leak Control

15. Main Fuel Valve (MFV) Leakage with On-Pad Abort
16. Purge Check-Valve Failure
17. Anti-Flood Valve Leak Detection
18. Fuel Preburner Oxidizer Valve/Oxidizer preburner Oxidizer Valve (FPOV/OPOV) Window Opening
19. High Pressure Fuel Duct Cracking
20. HPFTP Turbine Temperature Sensor Reliability
21. Gaseous Oxygen Control Valve Leakage
22. Controller Delay Line and Diode Block Failures
23. Hydraulic Actuator Servo Coil Redesign
24. Flight Acceleration Safety Cutoff System (FASCOS) Erroneous Vote
25. Baseline Flight Software

High Pressure Turbopump Blade Cracks: NASA assembled a team of 44 specialists from industry, universities, USAF, Rocketdyne, and NASA to analyze the three types of blade cracks observed:

1. HPOTP First Stage Shank Cracks
2. HPFTP First Stage Lobe Cracks
3. HPFTP Second Stage Face Cracks

This team will provide detailed review and evaluation of the design changes currently proposed for solving these blade-life problems. Because these cracks have been observed over a long period of time, considerable work has already been done to provide improved margins and cycle life.

HPOTP 1st Stage Shank Cracks:

- Cracks are caused by high-cycle fatigue
- Cracks initiate at small spots of subsurface carbides and other grain flaws
- Currently planned solution is use of a two-piece damper
- Further improvement in the future may result from the

use of a single-crystal alloy (PW 1480 SC) with the two-piece damper

The two-piece damper is expected to provide a cycle life improvement of about 10-times. It is currently in test with the standard MAR-M-246 material and should be certified for next flight use by October 1987.

HPFTP 1st Stage Firtree Lobe Cracks:

- These cracks are caused and propagated by low-cycle fatigue in the presence of hydrogen where a critical grain flaw porosity exists.
- The cracks can be monitored from one run to the next.
- Considerable structural margin exists even after a crack has propagated significantly. Therefore, they can be inspected for and the turbine replaced before the crack reaches anywhere near a critical depth.
- Several options are under test which will resolve this issue:
    - Custom-fitting to reduce strain levels
    - Shot-peening to reduce porosity
    - Hot-fire wheels to screen out susceptible blades
    - Use of PW 1480 SC single crystal blade material.

Whatever combination is finally selected, the safety margin can be expected to be high throughout any given engine duty cycle after inspection. The resolution of the problem is thus more related to life cycle and replacement costs than to safety of operation.

HPFTP 2nd Stage Firtree Face Cracks:

- Similar in cause to the first stage lobe cracks, these second stage turbine blade face cracks in the firtree area are the result of overstrain and initiate at surface carbide spots. They propagate by thermal stress loads and are accelerated by the presence of hydrogen.

- There is a reasonably high probability of initiating these in a blade root (5 percent) and they occur on first mainstage load cycle if they are going to initiate. They tend to be self-arresting but, if run for a sufficient number of duty cycles, can approach critical flaw size.

- Some of the corrective actions for the first stage blades are applicable to these blades and are being tested. These include shot peening, increased radius at the root, addition of a thermal barrier material, and plating. The single crystal material is also a good candidate.

- As with the first stage blades, the cracks arrest on each mainstage cycle. Therefore, conservative replacement criteria can be established that would provide high safety margins on any flight. The corrective design changes have leverage on replacement cycle costs.

Oxidizer Pump Bearing Ball Temperatures: The Phase II pump design with improved whirl margin, damping seals and bearing load sharing has provided greatly increased bearing wear life in tests to date. However, as a result of current studies of critical items and SSME acceptability for flight, a concern has been raised regarding the possibility of ignition of the bearing balls in the high-pressure oxygen environment. Close examination of the balls indicates dark surfaces along the normal run-line circle around the balls. These discolorations indicate potential local microsurface temperatures of the line of up to 1200-1300 degrees F.

Some cases result in dark bearing lines after only one full-power run while others gradually darken over four to six duty cycles. Several changes are planned to reduce the bearing loads and skidding as well as to improve the ball cooling. However, the only real safety issue is a potential for autoignition of the ball surface and a sustained metal combustion zone leading to pump failure and fire. This remote potential is being examined analytically and, to some degree, experimentally. It is the Panel's belief that the results of the experiments will be ambiguous, at best, and that statistical evaluation of the SSME's entire test and flight history can be used to make an adequate risk assessment. Combined with a large amount of other experience in ignition of metals in high-pressure oxidizers and, given the very high thermal diffusivity of a sphere to a line heat source, this SSME history provides a convincing indication of an acceptable configuration having a very low probability of sustained autoignition at least up to the 104-percent power level.

High Pressure Coolant Liner Buckling: This problem has been around for several years and has complex factors involved. First is the range of collapse pressures resulting from configuration variables such as wall thicknesses, weld mismatch, material properties, and actual operating temperature environment. Second is the variation in startup manifold transient pressures resulting from leakage of seals and use of dual pilots. At the bottom line for Phase II pumps, the coolant liner pressures at startup overshoot badly and this gets progressively worse as the seals wear. Many tests show overshoots at values equal to the buckling values for "worst case" configurations. This situation is unacceptable as the term "failure" should be defined, for purposes of risk assessment, as overshoot above those values that would result in a safety factor of 1.4 for the minimum dimension configuration.

The corrective action plan comprises several items:

1. Improved weld quality specifications and inspection techniques.

2. Reduction of nominal coolant liner pressure through re-orificing.

3. Redesign of the static seals' travel capacity to prevent plastic deformation causing current progressive leakage. The seal materials will also be changed to provide higher operating temperature without permanent deformation and protection from hydrogen embrittlement.

These changes and the certification of peak pressure margins of at least 1 1/2 times for the worst-case geometries should provide high confidence in flight safety.

Main Combustion Chamber Coolant Outlet Neck: The structural failure of the coolant outlet neck on engine 2308 in 1985 has led to a detailed re-examination of the specific design and fabrication control for this part. It also raised questions concerning the weld characteristics and inspectability and strength margin criteria for other similar zones in the engine. While tighter control of inspections and X-ray assessments can hope to catch non-fully configured areas in existing and future parts, it appears prudent to modify the outlet design for higher strength and fatigue margins.

The current design in work is based on using an electro-deposited nickel reinforcement layer encompassing all of the neck welds. The operating stress should be reduced by 50 percent. The dynamic stress in the fuel turbine duct region will, however, increase about 40 percent and this must be evaluated carefully, along with all other effects on the rest of the adjacent manifold regions. For the future beyond the next series of flights, a new one-piece machined outlet can provide added simplicity and better configuration control.

4000 Hz Pressure Resonance in Liquid Oxygen (LOX) Inlet Region:

This phenomenon has occurred only rarely in the history of the SSME. Observations on two engines in 1985 gave a more definitive indication of a potential failure mode and has resulted in an in-depth investigation of the causes and potential corrective design changes. The amplitudes of the vibration are very dependent on power level and, of course, the phenomenon became more apparent as a result of operation at 109 to 111-percent thrust. The frequency is independent of power level indicating a structural-hydraulic resonance coupling.

A careful survey of earlier engine data logs indicates that 9 out of 42 engines have exhibited the resonance at levels above 5 g's on the thrust-cone accelerometer.

The issue is not the vibration per se as it is confined to a small region of the engine's head end and, at 4000 Hz, does not propagate to nor stimulate any other significant structure. The concern is the result of a shift in frequency observed in several engines that has been traced to cracking of the splitter vanes in the inlet tee. This, of itself, is also not a safety issue unless the vanes can break off and a piece thereof get into the oxygen region of the main injector and cause distortion or plugging of flow.

The issue can be resolved in several ways. Engines which exhibit this phenomenon do so from the beginning of their life. Thus, they can be screened out and re-built in the inlet region. Although this may be costly, it will be effective. An alternative is to demonstrate that the way in which the vanes are attached to the manifold prohibits any detachment even after the (stress relieving) cracks occur. Thus, no safety issues would exist. Eventually, the vanes could be redesigned to incorporate a less resonance-inducing leading edge shape or, alternatively, the flow region could be otherwise detuned from the 4000 Hz band.

Precursor Program

The work on the Precursor program which, includes a number of significant improvements in engine hardware designed to provide significant improvements in margin above those of the Phase II and II+ programs, were found to be at a literal standstill. The two-duct power head and the wide-throat combustion chamber have been fabricated and an engine partially assembled. Testing of this new configuration is being held in abeyance because of funding limitations and the lack of test stand time availability.

Findings

An extensive re-examination of the design and test history of the SSME was conducted during 1986. The objective of the effort was to identify any safety issues that might have been overlooked in the past and to establish and validate an engine configuration for use in the next series of flights.

The engines planned for the next series of flights will basically be the Phase II engine configuration that was being certified for flight for operation at 109-percent rated thrust during 1985 and 1986. These engines incorporate many of the improved cycle-life turbopump components developed as part of the Phase II improvement program described in the Panel's 1984 and 1985 reports. During the testing in this program several additional issues arose and design modifications to resolve them will be incorporated in the "first flight" engines.

The results of the FMEA re-visit identified a number of areas where changes in hardware, software, redlines, or inspection criteria could reduce the probability or effect of certain failure modes. Such changes will be incorporated in the engines. As of November 1986, 25 such items had been identified. Of these, the more significant ones requiring resolution before flight are High-Pressure Turbopump blade cracks, High Pressure Fuel Turbopump Coolant Liner Buckling, Main Combustion Chamber Coolant Outlet Neck Cracks, and 4000 Hz Vibration phenomenon in the thrust-cone region.

Another issue relating to contact line temperature on the bearing balls in the High Presure Oxygen Turbopump is also receiving much attention.

The engine contractor is making considerable progress in developing a more useful risk assessment and margin validation methodology. This should result in an improved understanding of the safe operating regime of the engine and better control of the critical aspects of the engine configuration.

The Panel was disappointed to find that work on the Precursor (advanced margin) engine hardware is still proceeding very slowly because of limited funds and lack of test stand availability.

Recommendations

The changes described above primarily address hardware reliability, firmer redlines and configuration control and improved hardware cycle life. In only a few instances will there be any significant improvement in margin to failure. The Panel recommends, therefore, that the Phase II engine be constrained to operate at 104-percent rated thrust or less. Furthermore, it must be noted that a significant increase in operating margin of safety can be achieved by operating at 100-percent rated thrust. It would be prudent, therefore, to operate at 100-percent thrust until the Phase II engines have accumulated significant flight operating time so as to provide a meaningful data base.

The Panel recommends that the Two-Duct Hot Gas Manifold and the Large Throat Combustion Chamber be tested and certified as soon as possible. It is the opinion of the Panel that these changes will produce lower stress environments and improved margins at 104-percent and 109-percent thrust levels.

It is also recommended that NASA and its SSME contractor continue the development of improved methods for actually demonstrating critical operating failure mode margins and the more rigorous Risk Assessment analytical procedures. It is suggested that, as part of such procedure, the term "failure" be defined as a violation of any of the governing design criteria for a component rather than as an event such as structural failure or burn-through. By way of illustration, crack growth to the point where a calculated stress margin falls below 1.4X should be called a "failure" rather than when it reaches the "rupture critical flaw size."

E. Shuttle Computer Systems

Among the more complex parts of the Shuttle is its on-board computer system and there is concern that it could be a source of failure in some future Shuttle flight. As part of its overall activity in reviewing safety matters regarding the Shuttle, the ASAP has begun a review of this computer system. Two issues are of principal concern:

1. The configuration of replacement and existing computers to be used in future Shuttle flights.

2. General software development, change, and test procedures used with Shuttle software.

As our study was begun late in the year and it was not possible to contact all relevant parties during 1986, only preliminary observations are available at this point.

Computer Configuration

The current Shuttle computer system uses a set of five computers to operate the vehicle and the experiments on it. Four of the computers are connected in a tri-redundant configuration for high reliability. During critical phases of ascent and re-entry, all four of these computers perform the same operations. If deviations in outputs occur, the offending computer is disabled. In addition, the fifth computer acts as a backup system (making the whole system quad-redundant); it must be invoked manually by the crew and, once so invoked, control cannot be reverted to the primary system.

The hardware in the quad-redundant system has been adequate protection in all flights thus far. The worst actual flight case saw two of the primary computers fail. Once, in a pre-flight test, three of the primary computers failed. The source of each of these failures has been determined and eliminated from all other processors. There has never been a case in which it has been necessary to invoke the backup system.

The computer in use at present in the Shuttle has been obsolete for some time and its limited memory size severely hampers both experiments that people would like to perform during Shuttle flights and the size of flight changes. An upgraded version of the general purpose computer (GPC) has been designed and built. The new GPC is 2.5 times faster than the original, has substantially more (though still somewaht limited) memory, is smaller and uses less power. The original GPC has a mean time between failure (MTBF) of 5,000 hours. The new GPC is projected to be initially delivered with a 6,000 hour MTBF and it is expected that the flight systems will be at 10,000 hours MTBF.

The Problem: The onboard flight computer system will be upgraded using the new computers in late 1988 or early 1989 (corresponding, roughly, to STS-30 or 31). There are two proposals for configuring the new onboard computer system:

1. Use four of the new GPCs for the quad-redundant primary system and one of the original GPCs for the backup, i.e., 4/1.

2. Use the new GPCs for all five computers in the system, i.e., 5/0.

The two alternatives will be designated as the 4/1 and 5/0 designs, respectively. The use of either option involves operating system changes to both the Primary Avionics Software System (PASS) and the Backup Flight System (BFS).

The rationale for the first proposal is that there is considerable experience with the original computer and that by having two different kinds of processors (called "dissimilar redundancy"), the probability of a generic failure that causes loss of a mission is reduced. The arguments for the second are that the first choice forces a spreading of software verification resources among two systems, may complicate the operational procedures used, and may thus actually reduce the reliability of the primary system.

Discussion

The opinions of NASA and Rockwell personnel on the implications of the 4/1 and 5/0 choices vary considerably. The actual implications will depend upon budgetary considerations and testing and design decisions not yet made. There are several important considerations:

1. The ability to quantify the risk protection provided by using dissimilar hardware.

2. The extent and impact of necessary software changes.

3. The impact on software testing procedures.

4. The impact on operational procedures.

5. The ultimate configuration.

6. The relative reliability of the original and new GPCs.

Dissimilar Redundancy: Dissimilar redundancy is accepted by many in the aircraft industry as being an important method of guarding against generic faults. It is used in three operational, three experimental, and seven developmental aircraft types. It is, however, generally agreed that there have not been enough flight hours to verify or disprove its importance. Under the conditions that both the 4/1 and 5/0 designs are operationally equivalent and equally tested and verified, the 4/1 design certainly does provide greater protection (again, it is not possible to determine how much) than the 5/0. It is thus necessary to examine the differences in system operation and the levels of testing possible within cost constraints to try to deduce any difference in risk arising from operational and testing differences.

Extent of Required Software Changes: First, compare the software changes involved in a typical "Operational Increment" (OI): It is important to note that both PASS and BFS must be changed regardless of which option is chosen as it is desired to be able to reconfigure one of the new GPCs to function as a backup system in case of failure of the backup computer system and it is desired to maintain only two sets of code (PASS and BFS) and not three (as would occur if two versions of the BFS were kept). Thus, the basic software changes are the same for either the 4/1 or 5/0 choice. It is also important to note that, once changed, the BFS code will be able to run, unchanged, in either a new or old GPC. As shall be seen, the size changes required to accommodate the new computers are small in comparison to the changes that are normally made during a year's time.

Roughly speaking, the code in the PASS and BFS can be divided into two parts, the kernel code and the application code. The code associated with different applications is typically independent, while most applications make use of the code in the kernel. The system is thus more sensitive to errors in the kernel code.

The kernel code for the PASS requires only a 210-word (out of 104,000 words in the system) change. This code involves two kinds of functions: local delays and synchronization among the processors. On the other hand, operational instructions have involved changes to about 15,000 words of PASS code. Similarly, only 114 halfwords of code in the BFS must be changed, again to manage timing in a machine-independent manner. In this case, the changes only involve initialization code and no run-time code. Up to 7,000 words of BFS code have been changed in an operational instruction. Thus, the size of the operating system code changes to accommodate the computer hardware upgrade is only about 1.5 percent of the size code that has been changed (and tested) in an operational upgrade which occurs, normally, although this 1.5 percent is perhaps more difficult to code than much of the OI code and its affects a greater percentage of the system.

Software Testing: There are two areas in which the 4/1 configuration affects the system negatively and which must, thus, be weighed against the positive benefits of dissimilar redundancy in hardware. The first of these arises from the fact that in a 4/1 configuration, all changes to the BFS software must be tested in both the old and the new GPCs., This testing will occur during the flight software tests performed using the flight simulator in the Shuttle Avionics Integration Laboratory (SAIL). This testing phase is quite extensive and performed prior to every flight to test the software configuration for that specific flight. Thus, duplicate testing would have to be performed for all flights, not just once when the new configuration is introduced.

There are only two options with respect to testing a 4/1 configuration. Increase the level of testing for each flight or reduce the number of tests of the 4/1 configuration (in comparison to needs for testing a 5/0 configuration). An unknown at this point is the difference in testing requirements between the two configurations. JSC personnel do not feel comfortable in estimating this difference without performing a detailed testing plan. However, 10 - 15 percent would probably not be too poor an estimate. As flight simulation tests are very expensive, this difference represents a substantial amount of money. Equally important, it represents a longer turnaround between flights and would reduce the frequency of Shuttle flights (there is only one Shuttle Avionics Integration Laboratory (SAIL) facility and it is already in operation two shifts per day).

From the history of software and hardware failures detected during flight simulation tests, it would appear that a 10-percent reduction in testing could possibly result in missing the detection of a software failure sometime within 10-20 flights. Thus, NASA should pay the extra testing costs and not reduce testing if a 4/1 configuration is chosen. It would also be important that JSC personnel be protected from undue pressure to reduce or limit testing costs in the face of increased testing needs.

Operational Procedures: The second area of concern is the fact that the reconfiguration management in event of a BFS GPS failure is potentially more complex with a 4/1 configuration than for a 5/0 configuration. Again, the exact nature of the differences cannot be determined until additional design decisions are made in the future. Also, the opinions of NASA personnel about the nature of the changes is varied. It is possible that in the event of a BFS computer failure in a 4/1 configuration, one would be faced with either having the astronauts manually physically rearrange the computers in the system or fly the remainder of the mission without a backup computer. Either choice introduces additional risk.

It is also important to recognize that there is some increase in the level of complexity that the human astronauts must manage and that there has already been a near-disaster due to pilot error. It was mentioned above that during the STS-9 flight, two of the computers failed. One was re-started and placed back in service (but in a reconfigured system). When the Shuttle touched down, that computer failed again. When the pilot switched it out, he forgot about the reconfiguration and switched out a good string of one of the good computers. Had such an error occurred before touchdown, a major disaster would have been likely. This error occurred because of the complexity of the system operation. Increasing the complexity of in-flight operation does, therefore, increase the risk involved.

Ultimate Configuration: There are also considerations that arise with respect to whether or not a 5/0 configuration is adopted ultimately. If a 5/0 configuration is not adopted, the Shuttle will be flying for a long time with very obsolete hardware. This obsolete hardware is also aging and will eventually become unusable, at which point a 5/0 configuration seems inevitable (unless yet another generation of new hardware is added).

If a transition to a 5/0 configuration is ultimately made, there will be an additional round of modification, testing, and training involved and, hence, additional expense incurred.

Reliability of New and Old GPCs: It seems clear that, on paper, the new GPC is more reliable than the original but it does not have the flight testing of the original. All of the problems found in the original GPC have been corrected in both the current versions of the original GPC and the new GPC. If an original GPC is used, it will be a processor that has been in use for several years, not a new production copy of the original design. This has potential for both positive and negative effects. Through its use any initial manufacturing defects have been eliminated. However, as it has been in use for several years, one must question the effects of aging.

Findings

The principal factors between a 4/1 and a 5/0 configuration are:

1. The additional safety provided by dissimilar hardware (remember that there already is dissimilar software);
2. Human factor contributions to risk - part of the safety provided by the computer redundancy is achieved through astronaut training and in flight operations and maintenance procedures performed by the astronauts. There would be some differences in the training and in these procedures between a 4/1 and a 5/0, and correspondingly a difference in the risk introduced by human factors. This risk difference may well be greater than that in item 1 above;
3. The impact of the flight schedule on the software testing that will be possible, or stated conversely, the impact of the software testing (which is larger for the 5/0 configuration) on the flight schedule, and;
4. The additional costs required for a ~~5/0~~ 4/1 decision.

It is not possible to quantify the first of these. Though there have been a few claims regarding the second, there has not yet been a careful study of this factor. The third has also not been studied in detail, but 10-15% is a reasonable estimate. The fourth has also not been studied.

The second item has strong safety implications beyond the decision between a 4/1 or a 5/0 configuration. It is clear that some current operational and/or in flight maintenance procedures performed for the purpose of improving computer reliability may require the astronauts to do things in a different manner than that in which they were trained. This results in a significant additional risk, and has already resulted in a near disaster.

Recommendations

1. In order to provide greater confidence in the new GPC, it is recommended that the new GPC be flown on several flights as the backup computer. Since several flights are scheduled with the old GPC's before the changeover, this should be possible.

2. NASA should conduct a study of the human factors aspect of risk associated with in flight operations and maintenance procedures, particularly changes in procedures resulting from response to some failure. Included in this should be a preliminary design of the 4/1 procedures and training and an assessment of their impact.

Software Development Procedures

The software development procedures used are critical to the reliability and cost of the on-board computer system. As it is not yet possible technically to automatically guarantee the correctness of real-time embedded programs of the size and complexity of those running the Shuttle, extensive testing is essential. Techniques and languages have been developed, however, that ease the problem somewhat, reducing the cost and amount of manual testing required. The review of these activities for the Shuttle has just begun and has not reached a stage where useful comment can be made. This review will be a major activity of the Panel during the coming year. Among the concerns are the following:

1. The methods of determining and validating the 8,000 I-LOADS that must be defined for each Shuttle flight. These constants define the mission to be flown and are as important as the software and computers to the success of a mission.

2. Implications of proposed flight schedules on flight software testing on the SAIL facility. In particular, there are concerns that the increased flight schedules will force reduced per flight testing.

3. The methods by which software tests are generated. The quality of the resulting software is highly dependent upon these procedures.

4. The methods by which compiler upgrades are tested. The compilers translate the program written for the Shuttle into the code executed by the computers.

5. More detail on the redundancy management among the computers, in particular, timing and comparison methods.

6. General hardware and software support system upgrade policies. It is not clear that NASA has general procedures. In the aftermath of the GPC upgrade, it would be a good idea to examine this issue and encourage NASA to develop suitable procedures.

In addition to these technical concerns, there are several concerns about personnel matters:

1. The salary structure for technical persons within NASA is of concern. It appears that in order to progress in

terms of salary, people must move into management ranks, making it difficult to keep experienced, highly qualified people in the technical ranks. Moreover, it appears that the salaries of NASA technical people are substantially below corresponding industry salaries.

2. Much of the knowledge of Shuttle computer development and operation resides in the corporate memories of the employees who have worked on the system. The age distribution of the employees working on the computer system is of concern. There have been initial inputs that the current staff is heavily skewed toward the older age groups and that there is a dearth of employees in the mid-age group.

3. Some concern has been expressed about pressure from above to state that adequate tests can be performed within budget, whether or not they can be; it is also implied that if individuals do not conform, someone else will be found who will.

F. External Tank

At this time the External Tank is the Shuttle element that has been least affected by the activities undertaken in the aftermath of the Challenger accident. This is not to imply, however, that there have not been activities to ensure continued confidence in the External Tank. As with other elements of the Shuttle, a review and assessment of all the requirements for the External Tank is being made. This review includes design, test, integration, and FMEA/CIL hazards analysis. Thus far, no significant issues have surfaced although the External Tank Tumble System was the first subsystem to go before the Level II Program Review and Control Board for a waiver subsequent to the re-visit of the FMEA/CIL process.

G. Orbiter Landing Gear System

The Orbiter landing gear has been a subject of concern to the Panel and has been discussed in its reports since 1981. The Presidential Commission commented on this system and on other aspects of the landing phase in the section of its report entitled "Landing: Another Critical Phase." In this section the concerns discussed by the Panel were highlighted. NASA has responded to Recommendation VI of the Commission's report; the response meets the objectives of the Panel's earlier recommendations. The actions undertaken comprise test, operational, and redesign activities. The significant elements thereof are summarized below:

1. Operational:

a. Shuttle landings will be planned for Edwards Air Force Base until satisfactory structural safety margins have been demonstrated.

b. Gear load reduction by means of appropriate positioning of Orbiter elevons during the period from nose-wheel touchdown through high-speed roll-out will be implemented.

c. Planning will include the determination of optimum Transatlantic Abort sites including any needed upgrade thereof.

d. A runway overrun barrier is to be used at Dakar, Senegal.

e. Improved wind measuring equipment will be installed at both launch and landing sites.

2. Test:

a. Prior to first reflight, a heavyweight brake dynamometer facility will be assembled and used to verify braking capability.

b. High-energy "wear-ins" or "green-runs" will be conducted on brake assemblies.

c. Tests will be conducted to assess the characteristics and adequacy of the anti-skid system.

d. Tests will be conducted to determine braking capacity taking into account the maximum brake pressure capability and response time of the crew under the known post-flight physiological condition and capability of crew members.

e. Tests will be conducted to determine the feasibility and consequences of a "roll-on-rim" capability.

f. Tests to determine the effects of fifteen (15) knot crosswinds (completed).

3. Design:

A number of changes to the brake system will be designed and implemented. Among these are the following:

a. Thickened brake stators.

b. Modifications to balance brake system hydraulic pressures to eliminate the apparent 60/40 energy distribution between inboard and outboard brakes.

c. A six-orifice brake hydraulic system to alleviate hydraulic chatter that has been observed.

d. Stiffened axles to alleviate relative motion between stator and rotors to increase effective rubbing area contact.

e. The development and installation of a tire pressure monitoring system.

f. Develop tire improvements. Development tests are to be conducted at Langley Research Center and at Wright-Patterson Air Force Base.

Additional areas are being investigated as part of the effort to improve the Orbiter braking system. These areas have not, however, been designated as mandatory for first reflight. They include items such as use of an Orbiter drag chute, upgrading of nosewheel steering system, and wheel spin-up devices. Also, landing and roll-out simulations are to be conducted at the Ames Research Center flight simulators. The Panel will continue to monitor progress in these areas.

IV. Space Shuttle Operations

A. Launch Processing

The Panel has continued to review and assess the multitude of activities that comprise the preparation of the Shuttle for flight and the launch of a mission. Emphasis was placed this year on determining the effects of actions being taken to recover from the Challenger accident and the identification of areas that, in the Panel's opinion, might require added management attention and/or might affect the ability to achieve a safe first reflight on schedule.

In the course of its reviews, the Panel drew information from a variety of sources but concentrated its efforts at the Kennedy Space Center (KSC). As part of the review process, Panel members held discussions with more than 40 "hands-on" technicians, quality control inspectors, and schedulers. Detailed discussions were conducted with senior and mid-level managers from KSC and from the Shuttle Processing Contractor (SPC).

Among the subjects examined were the status of facilities and flight hardware; the organization of both the KSC and the SPC and changes that occurred, the effectiveness of internal and external communications of these organizations; the status of personnel training, morale, and motivation especially as affected by the stand-down from flights and by personnel reductions during this period; the logistics and safety, reliability, maintainability, and quality assurance activities; the results of the recent activities of the SPC Risk Review Board and Safety Advisory Board (these topics are covered in another section ot this report); and finally, the response to Presidential Commission recommendations.

Status of Facilities: There is much activity in process to bring the facilities at KSC to a state of readiness to support the program when flights are resumed. Among the major facilities, the following are of note:

1. Pad "B" is almost complete with all modifications considered necessary prior to the first re-flight. The latter include items such as rain protection system, ET vent, and debris plate changes.

2. Pad "A" modification projects are running behind those of pad "B". Because of the availability of pad "B" and a limitation of resources, there is a slower construction rate in effect for pad "A". Current plans indicate that construction work on this pad will be completed about December 1987.

3. Mobile Launch Platform Number 3 is in the activation process and will be placed in a "minimum maintenance mode" from February 1987 through September 1988.

4. The Orbiter Modification and Refurbishment Facility now has an operational readiness date of April 1989.

5. The Orbiter Thermal Protection System (TPS tiles) Facility has an operational readiness date of April 1987.

6. The contract for the Orbiter Processing Facility Annex is scheduled to be let in early 1987.

7. The Payload Hazardous-Servicing Facility is in work.

Operations: NASA has selected McDonnell Douglas Astronautics Co. to perform payload ground operations at KSC, Vandenberg AFB, and at Shuttle landing sites. It is anticipated that work under the contract can begin in early 1987.

The issue of weather forecasting has been under review for some time as it affects operations at KSC. The need for more accurate and timely weather data, particularly winds aloft and rain, has been apparent and became more apparent as the pace of operations increased. From this review has come a plan that includes support from the National Research Council. Among the items being pursued is a development activity that will examine the feasibility of using a specially instrumented aircraft to determine wind velocity and direction in near real-time as it flies a trajectory that approximates that of the planned Shuttle ascent. The technique in use for this purpose at present yields data that can be as much as 3 hours old. Under these circumstances it is necessary to make allowances for uncertainty in the persistence of the wind conditions in predicting the structural loads that will be experienced by the Shuttle during ascent. Obviously, reducing the allowances for such effects will improve the assessment of loads and permit more informed control of risk.

In response to concerns raised by the Presidential Commission, the Associate Administrator for Space Flight established a review team to examine and assess the implementation of the Shuttle Processing Contract at KSC. The team was to give particular attention to the relationship between the SPC contractor and the several flight hardware contractors. This team has begun its activity and the Panel plans to meet with this group to exchange views.

In response to a request from the USAF, NASA is evaluating potential use of Vandenberg AFB Shuttle facilities during the period of "caretaker" status, now estimated to extend to 1992 or later.

General: On the basis of the discussions described at the beginning of this section, the following observations are noteworthy:

1. The magnitude of the documentation required at KSC for a typical mission illustrates the complexity of the launch preparation and launch processes. There are some 3,000 separate documents required comprising some 200,000 pages. When the number of copies required are factored into the consideration, some 15 million pages of documentation are distributed for each launch! If a launch is "scrubbed", some 2-3 percent of the pages (i.e., 300 to 450 thousand) pages must be reissued.

2. Facilitating internal NASA communications continues to be a key ingredient for KSC to meet its goals. This is recognized by all those involved and as the operations organization evolves under the changing STS organization, senior management attention must continue to be focused on this area to be sure that the communications system does not lose its efficacy during the transitional period.

3. There is a substantial amount of unplanned and previously deferred work at KSC. This is particularly true for the Orbiters. This work must be carefully scheduled and accomplished.

4. It was observed that, with lay-offs completed, the morale of the employees, particularly those of the SPC, has improved. This could be a transient phenomenon if any further personnel reductions are not handled adroitly. Frequent impromptu visits by senior managers to the work sites are an effective means for maintaining morale and motivation among the "hands-on" personnel. This is also true when the tempo of activity increases in preparation for the resumption of flight.

5. Workers often expressed the opinion that training should employ real or equivalent hardware and situations so that

the trainee can attain proper understanding of the hardware, software, and procedures. It was also suggested that competent supervisors and/or engineers should give the technical training courses rather than a training staff considered to be unfamiliar with the "real world."

6. The "hands-on" personnel exhibited respect for and reported satisfactory relations with most engineers. There was, however, concern expressed about the lack of experience and/or ability of many of the newly hired engineers.

7. The concerns about the use of "shop aids" that had been expressed by the Panel have been addressed most effectively and thoroughly. All the organizations involved--KSC, MSFC, JSC, and their contractors--are to be congratulated.

There are no specific findings or recommendations to be made in this area, other than these related to Shuttle management set forth in Section II and the Executive Summary. Launch processing is a complex activity and requires constant attention and discipline, along with adequate budgets and schedules, to be effective and safe. The Panel will continue to monitor activities in this area during the next year.

B. Logistics

The subject of logistics has been thoroughly reexamined by NASA since the Challenger accident. The concerns expressed by the Panel in previous annual reports have been fully borne out by this review. One positive result has been the safeguarding of funds designated for logistics--they can no longer be "transferred" or "re-programmed" to satisfy needs in other areas. There remain important issues and problems that must be addressed forcefully and solved so that NASA can believe, with assurance, that it has established an effective logistics system for the long term. These issues/problems lead to the following recommendations:

1. Complete the procurement process for necessary spares.

2. Establish procedures for the control of cannibalization with the ultimate objective of eliminating the practice.

3. Establish control of the pipeline for the repair of Line Replaceable Units (LRUs), in particular, as well as for other components. This will probably include the need for a repair depot on-site at KSC. Although it will still be necessary to return certain sensitive units to the manufacturer for repair, the number of such units should be kept to a minimum.

4. Determine, as soon as feasible, the impact of the "Maintenance Safeguards" program. If there is a financial effect (i.e., increased spares requirements) necessary budget modifications should be made promptly.

5. Ascertain the effect of the planned maintenance program on logistics. Make necessary adjustments to spares required. If the maintenance program planning is not yet complete, do so promptly in order that the effect on spares requirements may be known and incorporated into the recovery plan.

6. Determine the effects, if any, of the results of the ongoing Shuttle Design Review program (if any) and factor them into logistics planning.

7. Re-examine and assess the logistics targets to ensure

that they are compatible with realistic flight rates.

8. Establish a program to determine which components, devices, or parts are no longer available or may become so as a consequence of the supplier going out of business or ceasing their manufacture. Establish an activity to obtain equivalent hardware.

9. Reduce pipeline turnaround times for all critical LRUs.

C. Shuttle Flight Simulators

The Shuttle flight simulator program requires an additional airplane because the current three airplanes are aging and will soon require major modification. The restart this year of the astronaut mission related training program will require the fourth airplane in order to maintain the proposed flight schedule. Although this is approved, it appears to be suffering from lack of top management attention.

Recommendation:

NASA Headquarters should ensure that this program is continued and completed in a timely fashion so that astronaut training will not be delayed or restricted.

V. SAFETY, RELIABILITY AND QUALITY ASSURANCE

A. The NASA System Safety Program

Following the Apollo 204 tragedy, NASA spent several years putting in place a basically new type of safety program. An organization was set up at Headquarters and the methodologies were developed for an overall safety program. These methods were incorporated into the various volumes of the NASA document NHB 1700.1 "NASA Safety Manual." Other documents describe "Reliability Program Provisions," NHB 5300.4(1A), and "Quality Program Provisions," NHB 5300.4(1B).

At the core of NASA's safety program was the idea of "risk management" through the control of "hazards." Residual hazards that could not be designed away would be controlled at least to the level consistent with program objectives and cost constraints. The definition and analysis of hazards associated with a system and its operation was to be performed by "System Safety Function." The level of hazard control was not always expected to be perfect, and a "residual risk analysis" would be performed to provide a "retention rationale" for continuing to operate.

In parallel with the "Systems Safety" activity was a "Reliability" activity. This function was basically concerned with establishing a data base for selection of components which would meet allocated failure probability requirements, performing "failure mode and effects analysis," establishing redundancy criteria and configuration definitions, maintainability criteria and life limits, and the preparation of "critical items lists," containing items with single-point failure modes which could cause catastrophic results.

In principle, the failure modes and effects analysis should be both a design tool to provide an impetus for design change and an evaluation tool of the final configuration to define the necessary control points on the hardware.

The identified "critical items" would require a supporting "risk assessment and retention rationale" in order to be included in the overall system configuration. The hazard analyses being performed by the system safety function and the failure mode analysis and critical item identification performed by the reliability function came together in the generation of Safety Analysis Reports (SARs) and subsequent retention rationale for the critical items.

A third element in the overall safety program was "Quality Assurance." This function, as defined by NASA, would be responsible for ensuring that the hardware and software produced for the system was produced in a controlled way and met all requirements of the quality control criteria documents. This assurance role also included supervision of personnel certification and establishment of non-destructive testing methods to detect flaws and non-conforming materials.

At the beginning of the Shuttle program, the basic system safety policies and methods to be used were established by NASA Headquarters and used many of the approaches evolved during the Apollo program. The responsibility to implement these requirements was tiered down to various program levels and centers by management instructions and other requirements documents. During the earlier development phases of the STS program, NASA Headquarters retained a daily strong role in directing the overall safety program. However, by the time of the Challenger loss, the Headquarters organization was only minimally staffed, and had basically only a limited review and audit function. They were essentially a Headquarters Level 1 staff organization with no explicit responsibility and corresponding authority for system safety engineering throughout NASA. Headquarters field representatives at the Centers began to report directly to the program managers, and were simply reviewing data and specific problem areas rather than leading a comprehensive safety engineering activity. Annual audits by Headquarters declined to biannual and became merely surveys of limited scope with minimal staffing.

The implications of this relatively weakened safety organization was highlighted in the President's Commission Report when they said in Chapter VII that "the Commission was surprised to realize after many hours of testimony that NASA's safety staff was never mentioned."

Discussion of the NASA Safety Program

The Panel recognizes, as does NASA, that modern hardware systems such as aircraft or weapons or the STS are not only incredibly complex, but usually demand high performance and, therefore, are subject to significant risk. The objective of a System Safety Program in any enterprise or organization should be to manage such risk to an acceptable level (not zero) throughout the operational life of the system. In our view, the elements of such a Total System Safety Program are comprised of the following:

1. System Safety Engineering
2. Program Quality Assurance
3. Operational Safety Doctrines

In some organizations the first two elements are sometimes combined into a function called Product Assurance and is many times organized and thought of as the "Quality Assurance and Reliability Function." Within the Space Shuttle Program they were grouped in 1979 (NHB 5300.4(1D-2)) into what is even now referred to as Safety, Reliability, Maintainability and Quality Assurance (SRM and QA). Experience teaches, however, that under this "ility" structure, the system safety function loses its "engineering" role. Further, as operated in NASA, it does not have the authority to ensure that safety is designed into the system, does not control the system safety validation, and eventually becomes an analysis, record-keeping and audit function populated with personnel having that type of background.

However, beyond the disturbing decline in safety engineering stature throughout NASA, we believe there are also issues with the basic methodology used to ensure that risks are adequately projected (quantitatively) and then controlled to the levels accepted.

The Presidential Commission recommended that NASA should review all Criticality 1, 1R, 2, and 2R items and Space Transportation System hazard analyses. NASA responded during 1986 by performing a massive rework of all Shuttle program failure modes and effects analyses, an update of the resulting critical items lists, and a review of all hazard analyses all of which continues today. Although this may have value in identifying any new critical failure modes that may have been missed earlier, or subsequently introduced through changes, the crucial problem with the safety methodology is not really the failure mode nor hazard identification process. The procedures used do indeed result in definition of the critical modes of failure and their resultant hazards, and also the hazards which result from external influences beyond the system hardware and software. The crucial issue with the process is the "retention rationale" used to accept the hazards and which justify a waiver for using Critical 1 and 1R items. In many instances the stated rationale is really only qualitative "rationalization."

Criteria for quantitative risk assessment and explicit definition of the operating constraints to which the waiver is subject are not explicitly required by NASA's safety program guidelines. Although the Panel is quite aware of the pro's and con's of trying to establish "likelihood" or "probability" of failure, we believe a more realistic quantitative assessment of the critical hazards is crucial to overall risk management. There are many analytical tools and test methods that can provide data for such assessments. Among the most important inputs are the validation of critical design criteria and the demonstration of actual margins to failure modes.

The Panel believes that NASA could achieve a significantly better level of Operational Risk Control by recognizing Safety Engineering as an engineering design and hardware/software validation function; that Program Quality Assurance is a "total configuration control" function; and that Operations Safety Engineering is an "operational doctrine and control function." Within such an overall framework, the System Safety Engineering function should be carried out within clearly established policies and guidelines by means of specific organizational units directly responsible to ten NASA Center Directors and operating under policies established by the new Associate Administrator for Safety, Reliability, Maintainability and Quality Assurance. This new Headquarters office must have more than the loose oversite role in overall safety exercised by the Chief Engineer's Office over the past few years. The Associate Administrator should be made responsible for NASA system safety engineering in the broadest definition of that function (see below) and given the authority necessary to impose safety methodology, policy, and approval authority for system implementation. NASA safety engineering personnel should be part of the NASA Headquarters organization, although they would be matrixed into the various programs and projects. Their professional stature, career paths, and rewards should be a part of a respected Safety Engineering organization.

The System Safety Engineering function skewers through the overall hardware and software engineering activities. Among other things it should embody the following elements:

1. Overall system safety analysis
2. Hazard analyses and relative risk assessments
3. Failure modes and effects assessments and critical item definition
4. Critical components and subsystems reliability analysis and redundancy criteria
5. Criteria for design safety factors and operating margins
6. Component validation and systems certification test program requirements and implementation criteria
7. Specification of all environmental constraints at every level to ensure control of the validated margins on each subsystem
8. Evaluation of all flight data and modification of operating constraints as required to stay within validated margin regimes

The reason the Panel recommends that Safety Engineering be responsible for establishing safety factor and operating margins criteria and for defining the component and system certification programs is that these areas have the highest leverage on overall risk assessment and control. To be made responsible for system safety without authority over all of these critical functions that control the real risks is not viable.

Mission Operations Safety Engineering should also be the responsibility of the Systems Safety Engineering Organization. The function of Operations Safety Engineering is to ensure conformance with the policies and constraints under which the mission operations of the system will be carried out so as to sustain the certified configuration. These policies and constraints should encompass launch commit criteria, flight validation policies, and environmental constraints. The overall NASA policies in this area should be the responsibility of the new Associate Administrator for Safety, Reliability, Maintainability and Quality Assurance.

The Safety Engineering Organization should not be responsible for NASA Occupational Safety which should be a totally separate function under a Health and Safety Organization. It is most important that the Safety Engineering functions in NASA be perceived and operated as a true engineering discipline. The engineers should have significant professional training in safety engineering methodology and be incorporated into the earliest phases of the planning and design phases of every major hardware system program.

The third element of overall program risk management is Quality Assurance. Quality Assurance should be viewed as a configuration control function. As such it provides the certified documentation that the hardware and software have been produced to the exact designs which delineate the validated and qualified components and integrated systems. The "configuration" includes all aspects of the hardware and software including the applicable environments which in any way influence the properties of materials or stress margins or temporal behavior of components and systems. This function should be performed by a separate Quality Assurance organization and should not be a part of the responsibility of Safety Engineering (although there is certainly an interaction). The Quality organization should be the direct line responsibility of each NASA Center (and, of course, each Contractor) with the Director of Quality Assurance reporting to a top level of management to retain its independence and full integrity. Its purpose is not to engineer but to control and assure. As part of this function it does control the entire set of final released engineering documents describing the complete configuration of the system.

In the fall of 1986, responsibility for policy and oversight of this function was also included in the new Associate Administrator's Office. This is important because overall risk management and total Systems Safety is dependent on the Quality Assurance function throughout NASA.

Findings:

At the time of the Challenger loss, the safety function at NASA Headquarters had significantly declined in both function and staffing levels from its early role in the STS program. The Panel's perception from many briefings, documents, and discussions was that it had become basically a reviewing and auditing activity with little explicit authority for establishing and implementing System Safety Engineering policy throughout NASA.

The Panel's investigations into NASA's safety engineering methodology led us to believe that even had the activities been fully staffed, there still remained questions about how effective the safety program could really be. ~~The safety engineering function has been basically lumped into a Safety, Reliability and Quality Assurance staff-oriented organization~~. At the present time, our ~~understanding~~ perception of the new office of safety, reliability, maintainability and quality assurance, is that it ~~is still~~ appears to be ~~basically~~ a staff function with responsibility to define roles, requirements, and organizational structures in safety, reliability, maintainability and quality assurance. Three fundamental weaknesses appeared evident. First, there was a lack of in-line responsibility and authority in a Headquarters organization for establishing and directing the safety engineering function. Second, the elements of the safety functions that were being done at various locations did not include responsibility for defining and controlling the

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validation and certification programs. Thus, there was no way that the safety organizations in NASA could take responsibility for assuring that failure mode margins were acceptably demonstrated nor assure that the hazard analyses on which the risk assessments were based were valid. Third, there was a conscious lack of quantitative approaches to determine failure-mode probabilities for the purpose of defining acceptable margins, nor for the relative likelihood of resulting system interactive hazards.

⇒ new TP from p. 77

Recommendations:

The Associate Administrator for Safety, Reliability, Maintainability and Quality Assurance should have full responsibility to establish a total Systems Safety Engineering program throughout NASA and be given the authority to assure its full implementation. A Systems Safety Engineering organization reporting to the Associate Administrator should generate the overall safety program policies to be followed. It would also define the critical safety design criteria to be used and the testing program methodology necessary to assure that those criteria have been properly validated. This Headquarters organization would also establish requirements and methods for performing overall system integrated hazards analysis and for the generation of quantitative risk assessments tied to controllability of failure mode margins and test and flight results.

Reliability, Configuration Maintainability and Operations Safty Engineering should be integral parts of this Systems Safty Engineering organization and it would provide policy direction for these functions throughout NASA. The definitions of policies and operating instructions for the Quality Assurance functions which are a vital part of risk management should also be the responsibility of the Associate Administrator.

The policies and implementation directives should be implemented by System Safety Organizations reporting to the Director's office at each NASA Center. As appropriate, personnel from these organizations could be matrixed into the various programs. A significant part of NASA funds to be spent in safety areas should be allocated directly to the Systems Safety Organizations. This would provide assurance that necessary safety engineering activities can be controlled independently of the funding tradeoff pressures which always exist within the programs.

B. Non-Destructive Evaluation/Quality Assurance

Special attention is being given to non-destructive evaluation (NDE) test methods to assure quality (conformance to the design and build methods) for critical items, e.g., the internal components associated with the various joints in the solid rocket motor. In support of accomplishing this a meeting of national experts was held at the NASA Langley Research Center (LaRC), November 20-21, 1986, to discuss techniques for non-destructive evaluation (NDE) for qualifying critical Shuttle components. LaRC's expertise lies in detection sensors, signal processing and enhancement and data interpretation techniques.

The measurement technologies which Langley Research Center believes are candidates for assessing many of the questions of Solid Rocket Motor integrity are related to acoustic and thermal propagation. Both of these appear capable of detecting the various bond line problems that have been identified as critical failures modes. X-ray techniques which may play an important role will take a number of years to be of value. The thermal methods seem, at this time, to be the most practical in that they can determine properties over large surfaces efficiently and effectively. For example, it has been shown by a major contractor that hot water can be used to heat the rocket motor case to "see" into the insulation with infrared imagers. LaRC tests have shown that one can determine quantitative physical properties of materials with a thermal NDE system consisting of scanning lasers, IR detectors, and computer controls and analysis models. However, the interpretation of the thermal data for the complexities of the solid rocket motor requires further lab testing. Ultrasonic energy is an ideal proble for finding debonds. However, the rocket motor geometry is more difficult to test since it consists of a steel case which is an acoustic resonator with insulation which is a laminated acoustic absorber. Recent tests by LaRC on a delamination problem of the X-29 R&D aircraft show that significant improvements in resolution can be achieved by methods which have the potential to remove the steel case from the signal and concentrate on the weak insulation energy.

The Panel recommends that NASA should emphasize development of NDE techniques for assistance in qualifying critical STS elements.

C. Reliability and Probabilistic Risk Assessment

There is a distinction between "reliability" which has a generally accepted definition as the probability a device will operate for a specified period under specified conditions, and "reliability engineering" which is a much broader and more appropriate term to describe a part of the design process. Reliability engineering is that portion of the design process which concerns itself with assuring that the hardware will perform as intended. It utilizes such analytical tools as the Failure Modes and Effects Analyses and the Critical Items List to focus designers' and management's attention on the relatively few failures which can have catastrophic results so that they can be eliminated from the design or their effects can be mitigated. There is also the responsibility for assuring that a vigorous process of recurrence control is applied to design related failures. It assures that proven or tested parts and materials are selected and emphasizes design techniques such as derating and redundancy. Reliability Engineering sometimes utilizes statistical tools to quantify probabilities. The concept of probability when one is dealing with extremely low probabilities is best described as a measure of the odds of a fair bet on whether or not the event will occur. These odds are usually derived from a combination of expert opinion and of operating experience, and change with experiences. As stated by Dr. Harold W. Lewis, in his paper "Probabilistic Risk Assessment Merits and Limitations":

> "It also serves as a systematic means for the quantification of the performance of a plant under upset conditions, and thereby is a means for the identification of weak points in design or operation . . . the major need . . . is a systematic purging of the conservative influence on the conduct of probability risk assessment, so that the results (including the uncertainties) are given generally understood meaning."

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APPENDIX 5

March 11, 1987

NASA ADVISORY COUNCIL

Report of the Task Force on Issues of a Mixed Fleet

National Aeronautics and
Space Administration

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of: LB

March 11, 1987

Honorable James C. Fletcher
Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Jim:

With your approval, the NASA Advisory Council established a Task Force on Issues of a Mixed Fleet to undertake an independent study of the principal issues associated with the employment of a mixed fleet of launch vehicles. The key questions addressed related to an appropriate mix of Space Shuttle and expendable launch vehicles, policies and practices for their use, and NASA's role in commercializing launch services. The Task Force has now completed its study and its conclusions and recommendations, strongly endorsed by the Council as a whole, are contained in their report, enclosed here.

Jasper Welch, who chaired the Task Force, has discussed the principal conclusions and recommendations with you, and Dale attended the Council meeting at which they were reviewed. I believe these are substantive conclusions and recommendations that warrant your careful attention. There have been enough good words on the value of a mixed fleet for NASA. We must now translate policy into action. The Council urgently recommends that NASA begin immediately, through a request for a supplemental budget, to provide sufficient ELV launch capability or service to achieve the robustness required for an effective space program. Without action now, the Nation's civil space program--especially that in space science, which has till now been a shining example of U.S. space leadership--will be damaged to a degree from which recovery will be extremely difficult and expensive.

Jasper and I stand ready to assist you in any way that we can, as do all the members of the Council.

Sincerely,

Dan

Daniel J. Fink

Enclosure

FINAL REPORT

NAC TASK FORCE ON ISSUES OF A MIXED FLEET

MARCH 1987

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Space Telescope Science Instutute

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TRW (Ret)

March 11, 1987

INTRODUCTION

The issues addressed to the NAC Task Force on Issues of a Mixed Fleet included three principal thrusts: 1) What is an appropriate mix of Shuttle and Expendable Launch Vehicle (ELV) services for NASA? 2) What are appropriate policies and practices for NASA to use in planning and providing launch services? and 3) What role should NASA play with respect to current efforts to promote further commercialization of space launch services? Appendix A contains the statement of issues in its entirety.

Many of the same issues and questions were being addressed in a parallel study by the NASA Office of Space Flight (OSF) Mixed Fleet Study Team. During the course of its deliberation, this Task Force received progress reports from the OSF study team, and was provided ample opportunity to comment on their findings. At the Task Force meeting held on 12 January 1987, the panel received a comprehensive briefing on the final OSF study results, as presented to the NASA Administrator.

It is the view of this Task Force that the NASA-OSF study has resulted in an exceptionally thoughtful, comprehensive, well-coordinated plan, which has addressed many of the detailed questions (in Appendix A) posed to the Task Force. The Task Force members endorse the "Key Conclusions" and "Recommendations" contained in OSF briefing dated 12 January 1987 (reproduced in Appendix B). However, some important reservations related to provisions for unscheduled delays in manifest planning remain; these are discussed in detail below.

The endorsement of the OSF study results has allowed this report to focus on the broader policy and "strategic" planning issues to be addressed by NASA as the Nation undertakes those actions necessary to re-establish a robust, resilient launch capability.

NATIONAL OBJECTIVES

It is imperative that the Nation's space program make essential contributions to national security, space science and technology, space exploration, commercial applications, and industrial strength. The space program should also be a source of pride for our citizens and a key contributor to our international prestige.

The U.S. space program is being challenged as never before. Europe, China, and Japan all have vigorous, expanding space programs. The Soviet Union is making its immense, long-standing space effort much more appealing and visible. It has offered space launch services at rock bottom prices with favorable arrangements, as it seeks to exploit the Western hiatus in space launch activity. It is strongly encouraging more scientific cooperation and collaboration with Western scientific institutions.

This Task Force believes that an infusion of new direction, dedication, and commitment is demanded if the U.S. space program is to remain competitive. Addressing this new level of international competition will require the commitment of additional financial, technical and managerial resources. NASA itself must be diligent in making every dollar count toward mission accomplishment. But there is no escaping the depletion of scientific and technical capital that has accompanied years of chronic underfunding.

NASA has recently confirmed its goals to achieve major advances in aeronautics, space science, and exploration of the solar system. These are worthy national goals for the civil space program, and are clearly NASA's responsibility. A robust launch capability is an essential prerequisite for these space goals.

Robustness, the "sine qua non" of space transportation, is measured by 1) the adequacy and sustainability of the launch rates, 2) the capacity provided to accommodate uncertainties and unpredicted requirements, 3) the ability to recover rapidly from stand-downs, and 4) the capability to launch a diversity of spacecraft including large and heavy payloads. A successful program must be managed to meet each of these requirements.

The Task Force believes that a robust program must include 1) adequate amounts and diversity of flight hardware and spares, 2) enough launch and integration facilities to absorb unexpected, but inevitable delays, 3) continuing development to improve reliability, reduce operating costs and increase capability, and 4) realistic planning and scheduling that faces up to the potential for delays and stand-downs.

The Task Force is immensely sobered by the enormous budgetary costs, opportunity costs and program disruption of the current unplanned for stand-down. The units are billions of dollars. This cost and disruption overshadows, in our view, the previous custom of evaluating launch services on a "cost-to-orbit-if-everything-works" basis.

SITUATION ASSESSMENT

The comments that follow relate only to the Task Force's assessment of NASA's recovery plans and projected sustained space flight operations performance. The circumstances leading to the current shortfall in launcher availability were not addressed.

The Task Force assumed continuation of the current policy that divests NASA of any responsibility to provide launch services for commercial communications payloads.

As discussed below, this Task Force recommends that NASA planning be based on a Shuttle operational flight rate of about 12 flights per year from KSC. However, this 12 per year should be a "robust 12" and will absolutely require a replacement orbiter, more spares and the best effort of good people.

Furthermore, the Task Force recommends that every effort be made to off-load payloads onto Expendable Launch Vehicles, ELVs. The off-load to ELVs in the near future is significant beyond just the increase in payload launched to orbit by ELVs. The OSF study found that high use of ELVs improved schedules for many, many payloads by two to four years, both for payloads that wound up on ELVs and those on Shuttles.

The OSF study reveals that, with these assumptions of 12 STS flights per year and high ELV use, the shortfall in launch capacity for NASA's missions, including the remaining support to the DoD, is approximately 7-8 equivalent Shuttle flights (11 percent) for fiscal years 1988 through 1992.

This shortfall in capacity remains in spite of 1) the termination of NASA's commercial launch activities, 2) the abandonment of 28 equivalent Shuttle payloads previously programmed for space science, exploration and applications, 3) the delay of the remaining science and applications projects by an average of approximately 3 years, 4) the diversion of many DoD spacecraft to Air Force ELVs, and 5) the off-loading of all ELV compatible non-DoD payloads to ELVs.

Furthermore, and perhaps most importantly, the analyses of the OSF study have assumed no Shuttle or ELV operational problems resulting in extended precautionary stand-downs for analysis and/or modification. Also, the assumptions concerning Shuttle cargo bay loading efficiency represent substantial improvements over historical performance.

The capacity deficit for the three-year period 1993 through 1995 grows to 15-16 equivalent Shuttle Flights (24%), indicating a deteriorating situation. This is, of course, partly a result of the Space Station construction and operational support demands.

Current OSF planning for the 1994 and following period calls for eight Space Station support flights plus four flights per year for Shuttle unique national security payloads. This would fill a 12 flight STS manifest, leaving no additional capacity for other missions, including non-Space Station science, on-orbit servicing, repair, re-boost and launch of new spacecraft.

The Task Force views this shortfall with measured but real alarm. The real requirements of the Space Station are being frozen by design decisions this year. Unlike a manifest of disjoint payloads, the Space Station launch demand comes as a single, very large requirement. Moreover, choices between Shuttle and ELV launch are being made this year for many post-1993 DoD payloads. Serious effort by NASA is clearly required in 1987 to resolve the post 1994 supply and demand for the Shuttle.

The Task Force believes that the science and exploration programs deserve special attention in the deliberations that lie ahead. They are at the heart of NASA's mission. They are spelled out in

NASA's charter. There is no one but NASA to ensure a healthy program. Space science and exploration provides a large measure of popular support for the space program as a whole. Substantial private and state government investments have been made in the research institutes that conduct these programs. The federal government has a fiduciary responsibility to these investments and to support the goals for which they were made.

FLIGHT RATE PLANNING FOR SHUTTLE

This Task Force did not make any independent inquiry into the achievable flight rate of the Shuttle. It notes that:

(1) The recent National Research Council study concluded that 11 to 13 flights per year is the reasonable upper limit expectation with four Orbiters;

(2) The NASA in-house planning with four Orbiters spans the range of 12 to 16 flights per year as the asymptotic rate through to 1995;

(3) The Shuttle payload weights are being adjusted downward to accommodate "down weight" requirements; and

(4) The rates in (1) and (2), above, assume no major disruption or fleet-wide stand-down.

The Task Force well understands that there are fixed annual costs associated with the STS operation. This has led many to conclude that, therefore, economics dictates that the Shuttle should be launched as often as possible in order to minimize per launch costs.

This Task Force does not share that judgement. Rather, we place primary importance on the enormous costs that are imposed on a (helpless) user community by delays in planned for launch dates. The post-Challenger stand-down has dramatized these delays, but we would draw attention to the fact that delays were common and expensive, even without such a major disruption.

That is, The Task Force believes that true economy would be achieved by 1) investing sufficient resources in the Shuttle to be able to support planned launch rates even if there are delays and precautionary stand-downs and 2) establishing planning criteria and processes that realistically deal with the nigh probability of unscheduled delays.

Following this philosophy, we recommend that the expected Shuttle flight rate be taken as a "robust 12" flights per year. This means 1) spares, facilities and other resources must be sized to accommodate 16 flights per year over a two to four year planning horizon, 2) launches are not promised at a rate faster than 12 flights per year, and 3) both payload and launch preparation be structured to stay ahead of schedule so that inevitable, unexpected delays with one mission can be handled without impacting other programs.

A flight rate of twelve is judged by the NRC study and OSF to be sufficient to keep the Shuttle operation vigorous. For the time period to the early 1990s there will be an adequate backlog of payloads to "supply" the Shuttle should rates above twelve prove comfortable to sustain.

But the thrust of the Task Force recommendation of providing a resource base for sixteen flights per year is to provide a surge capacity to 1) make up for periods when the baseline twelve was not achieved (miss one flight at a rate of 12 and it takes 10 months at 14 per year or 5 months at 16 per year to get back on schedule), 2) provide for "extra" flights to service or repair a satellite (e.g., re-boost of the Hubble Space Telescope will be needed on demand if the atmosphere is unduly heated at the next solar maximum), 3) provide insurance to protect space science missions which often require a very specific launch window for success, or 4) backup the ELV fleet if it has troubles.

CONSIDERATIONS GUIDING MIXED-FLEET POLICY

This Task Force believes that a robust space access program must include:

1. A launcher family that is diversified in size and type,
2. A manned launcher with two-way cargo and crew transfer capabilities,
3. Sufficient launch capacity in each launcher class to provide for continuing space operations during stand-downs for another launcher class,
4. Launchers with much larger and heavier payload capabilities than the Shuttle,
5. Sufficient capacity at launch and integration facilities to absorb unexpected, but inevitable delays without impacting other programs.
6. An aggressive launcher reliability improvement program,
7. A strong supporting logistic program for all launch elements, and
8. An aggressive policy of providing dual-launcher compatibility for high priority payloads.

The Task Force views the Shuttle as a critical national resource and an absolutely essential ingredient in the U.S. space program. Many space science missions are critically dependent upon the manned capability of the Shuttle. Furthermore, the Space Station program is clearly dependent on robust Shuttle support.

Therefore, the Task Force recommends a major evolution in NASA policy from one that has maximized the use of the Shuttle, to a policy that preserves the STS fleet for those critical missions that require its unique capabilities. These features include two-way crew transportation, manned on-orbit tasking and intervention, spacecraft servicing and reboost, and the ability to return cargo from space.

Inherent in this recommendation is the incorporation of a diversified family of expendable launchers in the NASA space flight program. Every effort should be made to transition cargo missions onto ELVs, even in cases where modification of the payload is required, in order to conserve the Shuttle for its prime mission, for which the Task Force sees plenty of demand.

While the Shuttle should not "compete" for cargo roles which do not require its unique capabilities, it should be available as a backup in the assured space access planning. In the future, high priority spacecraft should be designed for dual ELV or ELV-Shuttle compatibility, where technically and economically feasible. OSSA should also plan for a diversity of launchers and the use of dual-compatible spacecraft to assure continued access to space.

As indicated above, the Task Force recommends that manifest planning be based on a "robust 12" Shuttle flights per year, following the transition to full operational status. This recommendation assumes a 4-Orbiter fleet and a well-funded logistics program. To the extent feasible, all four Orbiters should include those special modifications required to support DoD missions--otherwise the DoD priority will likely force expensive delays onto other users.

Additionally, the planning and procedures should accommodate periodic stand-downs in each element of the ELV and manned fleets for problem analyses and resolution. Stand-downs (whether post-accident or merely precautionary) are extremely disruptive, costly beyond calculation, and represent the greatest single lien against achieving an adequate sustained flight rate. In-depth preparations are required to assure a rapid return to operational status following the identification of faults. NASA must emphasize recovery planning for all identifiable eventualities, including precautionary interruptions and accidents.

This panel recognizes that a major effort is underway to address the current Shuttle design improvements. Accordingly, it is reasonable that the planning assume that future problems are not catastrophic. Furthermore, the STS program has benefited from what is probably the most comprehensive reliability program ever instituted for a U.S. launcher.

NASA must anticipate, nonetheless, that problems will arise in both the ELV and manned segments of the fleet that will require extended stand-downs. For example, the Titan III booster has achieved a launch reliability of approximately 95%, which is fairly representative of ELV performance by the major suppliers. Based on the 31 ELV flights now planned over the period through 1995, the probability of accident-free operations is only 28%. If the failure rates could be reduced by a factor of two, the probability of failure-free operation would increase to only 53%.

In the Shuttle case, if one assumes a probability of successful operation of 99.5% (a failure rate 1/10 that being experienced by typical ELVs), then the probability of flying the 83 projected operations through 1995 without requiring a stand-down for analyses and/or design modification is only 66%. More to the point, a program goal of well over 99% will inevitably lead to unscheduled precautionary stand-downs.

Clearly NASA planning and budgeting should anticipate some level of problem generation at the flight rate anticipated during the next decade.

We should anticipate that the manned elements will suffer longer delays for problem analysis and resolution than the ELV segments (perhaps 6 to 12 months, versus the historical 2 to 8 months for ELVs). From a management perspective, the integrated launcher fleet should be assumed to be continually in some level of "recovery" and work-around involving schedule planning and problem resolution. Maintenance programs and modifications to upgrade performance will also contribute to intermittent loss of availability for segments of the fleet.

These issues cannot be wished away. Worst of all, failure to prepare for them pushes unexpected costs--budgetary and otherwise--onto the users of space transportation. This user community does not have any practical way of enforcing such preparation onto the launch services community. Hence, we must place the primary responsibility onto the launch services community and, in turn, upon NASA top management.

It must be recognized that the Space Station will consume a large fraction of the Shuttle manifest by the mid-1990s. The STS role is clearly essential for many of the supporting flights because of the need for manned tasking and intervention, and requirements for two-way crew and cargo transfer. The Space Station is destined to provide a demanding test of the adequacy of Shuttle operational planning. NASA must take those steps required to assure its availability.

On the other hand, the Space Station planning must be revisited. The Station should not expect to routinely use the Shuttle for delivery of cargo to orbit, nor can it specify today its need for unexpected crew and cargo rotation, nor can it count on Shuttle operation without stand-downs. This is the year for the Space Station to develop realistic plans and designs to deal with these unavoidable uncertainties.

The Task Force recommends that, in order to further off-load the Shuttle, the DoD be urged to divert as many of the remaining payloads as possible to the ELVs. The OSF study shows that the DoD is requesting about 50% of the Shuttle manifest in the 1988-1992 planning period, and over 40% of the manifest in the critical 1993-1995 timeframe (assuming 12 flights per year). It is clearly not possible to provide this level of support while meeting Space Station demands plus the critical science requirements; e.g., servicing and reboost.

It is apparent, following detailed discussion of the Task Force with senior representatives from the major launch vehicle suppliers, that the industrial capacity for ELV boosters in the U.S. far exceeds the most aggressive requirements projections (after a 3- to 4-year recovery period). This Task Force would note that a systematic development program to increase the reliability of current ELVs would be beneficial. Now that there is the general recognition that ELVs are to be used over the long run, such programs should garner support.

SUGGESTED POLICY FOR NEAR-TERM PROCUREMENT OF ELVS

NASA should, of course, take maximum advantage of the DoD's Titan IV (CELV) and Delta II (MLV) procurements, as well as other "available" expendable launchers, to meet their total near-term requirements. In pursuing this course of action the Task Force is concerned with approaches that include "innovative procurement" such as "minimum oversight, launch services" and "joint programs" such as having the Air Force "buy ELVs for NASA." These may well lead to unnecessary delays and, ultimately, substantial extraordinary NASA management effort to execute an otherwise straightforward procurement of available ELVs.

Accordingly, the Task Force believes that NASA should contract directly with the suppliers selected by the DoD, rather than using the Air Force as a procurement arm. This is viewed as an important factor in assuring focused management responsibility at NASA and at the contractors. The cost benefits from the combined NASA/DoD orders should be retained and available to both organizations. This will require a negotiated set of common requirements, including documentation, inspection criteria, etc., in order to achieve the full potential cost savings.

NASA management of upper stage procurement is viewed as particularly critical, because of the close ties between the upper stage and the payload.

The Task Force strongly recommends that ELV procurement provide adequate capacity to ensure flexibility and responsiveness to stand-downs for the various launchers. This will also improve the availability of the Shuttle to support on-orbit contingencies and service requirements. This is of great importance to the Space Station and several science payloads.

This added capacity should not only include procurement of additional ELVs and appropriate logistical support, but also some form of "surge" capability--for example, through contractual options with incentive fees for early delivery.

The Task Force recommends that launch vehicle cost, while important, should not be the dominant criterion in the vehicle selection and planning processes. Launcher reliability and availability are clearly more important in light of the relative lower costs of launch services when compared with the costs of spacecraft procurement and mission operations. This is further emphasized by the huge costs imposed on user and launcher communities by an extended stand-down.

The Task Force strongly recommends that NASA retain its launch services and payload-upper stage integration management roles in the near-term, because of the urgency of flying the accumulated backlog of payloads. A change of management roles, even if desirable in the future, would inevitably lead to further schedule erosion in the next three or four years. The practice of contracting appropriate launch services and integration support to industry should be continued and, where possible, expanded.

The Task Force is concerned that recent launch planning assumes no launch or integration facility improvements or expansions. But a robust space transportation system must be able to accommodate precautionary delays of one vehicle and payload without impacting others. Accordingly, the Task Force recommends that a study should be performed on an urgent basis to assess the constraints imposed by the current complement of launch and integration facilities at the Eastern and Western Test Ranges. This must, of course, be convolved with the selection of ELVs for the overall NASA, DoD and commercial requirements.

This study should lead to an integrated NASA/DoD program to construct any needed additional facilities. The time and cost required to remove constraints imposed by facility limitations are clearly minimal, when compared with the program costs associated with launch delays. A budget place-holder should be inserted now.

The Task Force also recommends that a study of upper stages be undertaken to ensure that adequate attention is given to this element of planning. This study is, of course, highly dependent on the detailed launcher strategy, and, as such, should be an integral part of the overall space transportation planning.

LONG TERM MIXED FLEET CONSIDERATIONS

The Task Force takes note of the long-term trend toward larger and more complex spacecraft for communications, national security/defense and science. Not all spacecraft will follow this trend nor should they. But for certain missions the trend is strongly driven by cost relationships, as well as technical considerations. For many commercial communication applications, earth station operating costs, including data processing and dissemination, dominate spacecraft and launch costs and clearly favor supporting a smaller number of large payloads, rather than a larger number of small spacecraft. For science spacecraft, many will remain small, but the larger ones grow ever larger. This trend is probably irreversible and, to the first order, is not influenced by launch cost.

It should be noted that the larger, more complex payloads exacerbate the launch planning and scheduling problems, since they are more subject to development delays. They are also more likely to tie-up integration facilities while unexpected problems are being addressed.

A Heavylift Expendable Launch Vehicle (HELV), with a payload weight well in excess of the STS, will be required in the next few years, not only to accommodate cargo requirements exceeding STS capabilities, but also as an alternative and backup for the Shuttle to allow off-loading heavy payloads which do not require man's presence. Heavier loads to LEO would reduce the transit time for planetary probes to Mars and the outer planets to typically one year from the present three or more years--with attendant reduced mission costs.

An HELV program is attractive to the Task Force for these reasons:

1. Provides the size and weight needed by overall mission considerations.

2. Contributes to national prestige through its enormous lift capability.

3. Protects the Shuttle from missions requiring large lift, but not requiring Shuttle's unique capabilites.

The Task Force made no effort to recommend among alternative HELV approaches, but noted that a Shuttle-derived vehicle (SDV) would seem to offer the following features:

1. Adds a new expendable launch vehicle providing backup for Titan IV class payloads. The SDV would exhibit failure modes independent of other ELVs, and would largely avoid failure mechanisms associated with the Orbiter and its man-support subsystems.

2. Provides a major increase in throw-weight at a potentially modest cost and with a short development schedule.

3. Provides additional production of common-use Shuttle components, thus reducing Shuttle operational and procurement costs, while improving the spares inventories.

4. Contributes to the large cargo capacity required for Space Station construction, and on a compatible time scale.

5. Achieves substantial compatibility with the existing and planned Shuttle integration and launch facilities (a benefit and a penalty).

6. Addresses the trend toward very large spacecraft, perhaps an additional 30,000 lbs to LEO.

7. Benefits from an exceptionally comprehensive Shuttle reliability program.

8. Achieves lower operating costs by sharing launch crews and facilities with the Shuttle.

9. Allows Shuttle design modifications to be flown initially on the SDV without risking the crew. This could substantially accelerate the incorporation of design changes.

The Task Force recognizes that most designs for heavy-lift launch vehicles, including Shuttle-derived designs, are promoted as offering more economical cost-per-pound-to-orbit. Such claims are undoubtedly true. This potential is an added bonus. Our interest lies in the considerations set forth above, and we would recommend an HELV program even without the lower cost-per-pound-to-orbit.

For those who believe launch costs, narrowly defined, are pivotal, we would note that a short, less costly development program is more easily and more surely amortized than a longer, more costly one.

The Task Force, while making no recommendation relative to a specific HELV implementation, does strongly suggest that NASA include a new heavy-lift vehicle in their planning. Furthermore, this panel feels that a Shuttle derivation deserves detailed evaluation and consideration.

The Task Force noted with interest that press reports indicate that the Soviet "mixed-fleet" planning includes a rich mixture of conventional ELVs, a "space shuttle" with a 30,000 KG payload capacity to LEO, plus a shuttle-derived HLV capable of boosting 100,000 KG into LEO. (Signal, December, 1986)

As one projects launcher requirements farther into the future, it is clear that an aggressive, comprehensive technology program will be required to ensure U.S. preeminence in high-end booster capability. The Task Force commends a model for NASA's consideration in which NASA assumes responsibility for sponsoring a broad research program which would be coupled to vehicle developments by NASA and the DoD to their own unique mission requirements. This is analogous to the current aeronautics modus operandi.

NASA-DoD COORDINATION

Budgetary constraints and schedule considerations will continue to demand extensive use of common launch systems for NASA and DoD missions. As NASA incorporates a significant ELV fleet into its program, a new level of collaboration with the DoD will clearly be required. The demands on the shared facilities at ETR and WTR are destined to strain the capacity at these key sites. Furthermore, as the nation contemplates the development of new boosters and upper stages, there will be increased emphasis on assuring their applicability to the needs of both organizations. This is an environment that could lead to a level of interagency competition that the Nation simply cannot afford. What is needed is a steadfast attitude of mutual trust and cooperation.

Therefore, this Task Force strongly recommends that the Secretary of Defense and the NASA Administrator develop and sign a Memorandum of Understanding (MOU). This MOU should define the relative roles, responsibilities and authorities of the DoD and NASA, at all organizational levels that interface in the development, procurement and management of common-use launch systems. In particular, the MOU should cover the conduct of launch operations, including the criteria to be used in designating the Mission Directors.

NASA's ROLE IN PROMOTING COMMERCIAL SPACE TRANSPORTATION

The Task Force heard presentations by representatives from a number of companies with commercial space transportation aspirations, as well as by senior officials from the various Government agencies involved with these activities. The panel was exposed to a remarkably wide range of views, considerations and planning maturity related to potential commercialization initiatives. This was coupled with an exceptionally diverse set of definitions for what constitutes a "commercial" launcher and/or launch services activity.

Considerations that, in the opinion of the presenters, bear on defining the "degree of commercialization" include:

1. The ability of the supplier to negotiate a contract directly with the user, with Government intervention limited to regulatory roles.

2. The ability of the supplier to perform on the contract with essentially no Government involvement.

3. The degree to which the associated manufacturing is free from Government-imposed documentation and inspection requirements.

4. The degree to which the flight and ground-support hardware developments were financed by private sources.

5. The degree to which the associated contracts provide for a payload delivery into a specified orbit for a fixed price, with launch failure liability limited by the terms and conditions of the contract.

6. The degree to which third-party liability and payload indemnification insurance is provided by non-Government sources.

The Task Force chose, for the purpose of their deliberations and comment, the following definition for a commercial space transportation activity:

> "The direct industrial sale of launch vehicles and/or launch services to non-Government users, where the U.S. Government involvement is essentially limited to regulatory roles."

The Government, of course, has always procured launch vehicles and launch support from industry. The manner in which Government procurements differ from "commercial" purchases clearly relates to the "terms and conditions" incorporated in the contracts. The definition suggested above does not suggest that the Government cannot take advantage of the development of a commercial space transportation industry. This would be accomplished by modifying the terms and conditions of the contracts to more closely emulate those incorporated in their commercial counterparts (to the extent this is found to be in the best interests of the Government).

However, the Task Force strongly recommends that, in light of the enormous leverage launch operations have on overall program costs, NASA not increase the risk of launch failure by significantly reducing their management oversight. As was noted above, launch costs are typically a small part of overall program costs, but the costs associated with program delays can be large. Moreover, the Government self-insures its own payloads and those science and applications payloads it sponsors at non-Government research entities. For such payloads the Government must assume a risk protective posture. Commercial payloads can, and do, provide their own payload insurance. The Government oversight role cannot be justified as insurance in these cases.

The Task Force believes that if a significant commercial space transportation industry were to develop in the near term, it would most likely germinate under one or more of the following circumstances:

1. Launchers or launch services developed under Government sponsorship being offered to non-Government users on an incremental cost basis (with appropriate Government approvals).

2. Launchers or launch services with very limited payload capability, developed with private financing, being offered on a strictly commercial basis to low-end users where launch costs are a pivotal consideration.

3. Launchers or launch services targeted on a specific application for which a major user, commercial or governmental, contracts upfront for a large enough initial order to justify a new launcher development.

The benefits potentially accruing from commercialization would appear to include:

1. A strengthening of the associated U.S. industrial base.

2. Reduced procurement costs for the U.S. Government, derived largely from increased manufacturing volume.

3. Minor improvements in U.S. balance-of-trade from associated foreign sales.

4. Increased industrial innovation in the areas of reliability and cost, as the participants address market competition.

5. Larger industrial investments to improve competitiveness and performance.

6. Enhanced national prestige, if the ventures flourish.

The penalties associated with an aggressive program to support the establishment of a viable activity in the private sector could include:

1. Exacerbation of launch pad and integration facility constraints in the near-term.

2. Increasing the potential for priority conflicts between Government procurements and their commercial counterparts, whose fixed-price structure may attract substantial corporate management attention.

The overall tradeoff would seem to favor stimulating commercialization, with appropriate attention being given to the risk issues.

The data presented to the Task Force indicate that the available launch services market, following fly-off of the current backlog, is likely to be relatively small and highly competitive. There is clearly excess capacity on a world-wide basis for payloads in the small-to-intermediate weight class. Foreign subsidization, "flexible" pricing and financing policies, and national prestige issues are among the factors complicating the marketplace. Furthermore, increasing requirements for foreign trade "offsets" and in-country participation are likely; all of these factors will make it difficult to achieve the benefits of scale. On the other hand, several of the current foreign boosters are experiencing reliability and availability problems, which may increase the potential U.S. participation in the market.

The Task Force supports a policy which allows U.S. industry to address those market segments which are found to be sufficiently attractive to warrant private investment. The Government should support this commercialization by incremental pricing of support activities (e.g., launch site support), and should permit and encourage the private sector to use relevant Government facilities. The Task Force views the current policy statements and negotiations with industry on these matters to be appropriate and encouraging.

This Task Force recommends that NASA neither encourage nor discourage the development of "system operators," whose role is to facilitate the interfaces among the commercial spacecraft or services contractor, the launch services contractor, the finance community and the insurance firms. If this industry is needed by the participants, it should be allowed to develop.

PRINCIPAL CONCLUSIONS AND RECOMMENDATIONS

This Task Force believes that the reconstitution of a robust, resilient, flexible space transportation system deserves the highest national priority. Furthermore, it has concluded that NASA policy evolution, as well as major program initiatives, are required to achieve this objective.

The principal recommendations are summarized as follows:

1. The Shuttle must be recognized as a national resource of enormous importance to the U.S. space program. NASA policy should evolve from one that has maximized the use of the STS to a policy that preserves the Shuttle for those missions requiring its unique capabilities.

2. NASA should, on a most urgent basis, initiate a program to incorporate a diversified family of expendable launchers into its space flight program, to include a Heavy-lift ELV. Payloads should be off-loaded from Shuttle onto the ELVs wherever possible.

3. NASA planning should be based on a "robust 12" Shuttle flights per year, following the transition phase to full operational status. This recommendation is contingent on a 4-Orbiter fleet and a sound logistics program sized to support a "nothing-goes-wrong" surge rate of 16 flights per year.

4. NASA planning should be modified to accommodate unexpected, precautionary stand-downs for all manned and unmanned vehicle types. Sizing of ELV and STS procurements must reflect this realism. Additionally, NASA should develop a program to substantially accelerate recovery from stand-downs.

5. The Secretary of Defense and the NASA Administrator should develop and sign a Memorandum of Understanding (MOU), which defines the relative roles, responsibilities and authorities of DoD and NASA elements in the development, procurement and management of common-use launch systems.

6. A study should be initiated to evaluate the constraints imposed by the current complement of launch pads and integration facilities on launch rate, surge capability, absorption of delays, and accelerated recovery from stand-downs. The study should provide recommended actions to substantially alleviate any identified limitations.

7. A study should be undertaken to evaluate the robustness of the upper stage vehicle fleet to exploit fully the diversified launcher family.

8. The Government should encourage commercialization activities, but should not directly subsidize such developments.

APPENDIX A

CHARTER

NAC TASK FORCE ON ISSUES OF A MIXED FLEET

October 9, 1986

NASA ADVISORY COUNCIL

STUDY OF ISSUES OF A MIXED FLEET OF LAUNCH SYSTEMS

TERMS OF REFERENCE

Background

Formal statement of national policy on space launch vehicles is under development by the Administration. It appears, as a consequence of the Challenger accident and the reassessment of Space Shuttle capabilities, that the policy, when established, will include elements of the following:

- The U.S. national space launch capability will be based on a balanced mix of launch systems, consisting of the Space Transportation System (STS) and expendable launch vehicles (ELVs). The elements of this mix will be defined to support best the mission needs of the national security, civil government, and commercial sectors of U.S. space activities.

- The unique STS capability to provide manned access to space will be exploited in those areas that offer the greatest national return. The STS fleet will maintain the Nation's capability to support critical programs requiring manned presence and other unique STS capabilities.

- The DOD will develop and operate a complementary expendable launch vehicle (ELV) capability for national security missions.

- The U.S. will encourage and facilitate commercial ELV operations by: (1) procuring ELV services from the private sector when appropriate, (2) launching foreign and commercial payloads with the STS only when the payloads are Shuttle-unique or have national security or foreign policy implications, and (3) minimizing government regulation of commercial ELV operations.

NASA launch vehicle policy has evolved to follow national policy. NASA will conduct its space flight program with a mixed fleet, employing both the Space Shuttle and ELVs, depending on respective capability, schedule, or other special need. NASA will also cooperate with other responsible organizations to assure that the total U.S. space launch capability (both government and commercial) includes the needed complementary launch systems.

Issues Raised

The mixed fleet concept leads to fundamental issues that need to be addressed. Included are such questions as:

- What is the proper mix of Shuttle and ELVs for the present NASA program and that planned for the next several years?
  - What criteria should be used for selection of launch systems for NASA missions: capabilities, schedules special factors such as need for human, Centaur, RTGs?
  - What mix of Shuttle and ELV missions does this yield for the NASA flight program (with allowance for Shuttle flight of required DOD payloads)?
- How is a "commercial ELV service" defined? What is the extent of the service? How are specifications set and met? What arrangements must be made for the use of government-owned facilities? What additional requirements must commercial operators meet, such as insurance, safety, etc.?
- What is the likelihood of being able to acquire from commercial sources the full NASA-required ELV capability necessary for the mixed fleet activity?
  - What must NASA do to stimulate a viable U. S. commercial ELV industry? Is some form of support required? What are the different modes of support that NASA--and the government--could employ for the industry?
  - How can a private U.S. ELV industry compete internationally with foreign government-subsidized launch systems?
  - How can a private U.S. ELV industry meet the full set of requirements (e.g., liability, safety, etc.)?
  - What is the relationship of the DOD and its program for complementary ELVs to a commercial ELV industry? Will this be an appropriate model for NASA? If not, what is a good model for the NASA's relation to an ELV industry?
  - If other departments and agencies are involved in stimulating a commercial ELV industry (DOT, DOC), how should NASA interact with them?

- If a private ELV industry is not viable, how should NASA work to assure the necessary U.S. launch capability for both government and commercial payloads?

The purpose of this study is to examine these and other relevant questions and develop recommendations for NASA actions.

Task Force and Membership

The NAC Informal Task Force for the Study of Mixed Fleet Issues is established to conduct the Study. The Task Force is to be chaired by Jasper Welch, at-large member of the NASA Advisory Council. Members and staff are listed in the enclosure.

Schedule

The study will be conducted beginning in October 1986, and should be completed by about February 1, 1987. A final report should be submitted to the NASA Advisory Council for its consideration prior to its February meeting.

Cost

It is anticipated that the conduct of the study will cost about $10,000, all in travel funds for the travel and subsistence of members.

APPENDIX B

NASA MIXED FLEET STUDY
CONCLUSIONS AND RECOMMENDATIONS

OFFICE OF SPACE FLIGHT
NASA MIXED FLEET STUDY
SUMMARY

KEY CONCLUSIONS

- MIXED FLEET REQUIRED
- NASA LAUNCH CAPABILITY NOT ROBUST EVEN WITH HIGH ELV OPTION

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OFFICE OF SPACE FLIGHT

NASA MIXED FLEET STUDY

RECOMMENDATIONS

POLICY

- ASSURE ACCESS TO SPACE
- UTILIZE MIXED FLEET TO:
  - -SUPPORT NASA MISSION REQUIREMENTS
  - -PROVIDE DUAL LAUNCH CAPABILITY FOR CRITICAL PAYLOADS
  - -EXPAND NATIONAL LAUNCH CAPABILITY
  - -PROTECT SHUTTLE FLEET -- A NATIONAL RESOURCE
  - -FOSTER ELV COMMERCIALIZATION

SPECIFIC

- IMPLEMENT "HIGH ELV" MIXED FLEET OPTION (FOR PAYLOADS THROUGH 1992)
  - -GENERATE EXTERNAL SUPPORT (e.g., OMB, CONGRESS, SIG)
  - -PREPARE BUDGET SUPPLEMENTAL / AMENDMENT
- FORMULATE MIXED FLEET IMPLEMENTATION PLAN
- ASSURE SAFE SUSTAINABLE SHUTTLE FLIGHT RATE

APPENDIX 6

Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization

Prepared by a Panel Convened by the

Committee on NASA Scientific and Technological Program Reviews
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
October 1986

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

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Preface

The Committee on NASA Scientific and Technological Program Reviews was created by the National Research Council in June 1981 as a result of a request by the Congress of the United States to the National Aeronautics and Space Administration that it establish an ongoing relationship with the National Academy of Sciences and the National Academy of Engineering for the purpose of providing an independent, objective review of the scientific and technological merits of NASA programs whenever the Congressional Committees on Appropriations so direct.[1]

To date five tasks have been undertaken.[2-6] The sixth task, which is the subject of this report, resulted from a request by the House Committee on Appropriations to the NASA Administrator in late April 1986 for an examination of space shuttle flight rates and utilization following the loss of the Orbiter Challenger (Appendix A).

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[1] Congressional Conference Report 96-1476, November 21, 1980.

[2] National Research Council, The International Solar Polar Mission--A Review and Assessment of Options, 1981, National Academy Press, Washington, D.C.

[3] National Research Council, Aeronautics Research and Technology--A Review of Proposed Reductions in the FY 1983 NASA Program, 1982, National Academy Press, Washington, D.C.

[4] National Research Council, Assessment of Constraints on Space Shuttle Launch Rates, 1983, National Academy Press, Washington, D.C.

[5] National Research Council, Review of NASA's Numerical Aerodynamic Simulation Program, 1984, National Academy Press, Washington, D.C.

[6] National Research Council, Assessment of Candidate Expendable Launch Vehicles for Large Payloads, 1984, National Academy Press, Washington, D.C.

At its meeting on May 16, 1986, the Committee nominated a panel to undertake the task. The areas of expertise sought included launch vehicle systems, airline operations, propulsion systems, aerospace logistics, and user requirements--space station, military, space science and applications, and commercial.

In appointing such a group of individuals to make scientific and technical assessments, it is essential that most have a high degree of knowledge in the subject of the study. Since such individuals may appear to have a potential for bias, every effort was made to achieve a balance in backgrounds and attitudes of the panelists in order to present as objective a report as possible.

The short period during which the review had to be undertaken put severe demands on the Chairman and members of the panel, who deserve much credit for their effective and timely response.

Norman Hackerman
Chairman, Committee on NASA
Scientific and Technological
Program Reviews

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Introduction

Background

The space shuttle had 24 successful flights beginning with the Orbiter Columbia in 1981 until the Challenger accident on January 28, 1986. The Challenger loss caused a general reassessment of the space shuttle program.

The Presidential Commission on the Space Shuttle Challenger Accident in its report made several recommendations that included a redesign of the Solid Rocket Motor, a review of critical items in shuttle components, and several aspects of safety. NASA formed a large number of in-house and contractor teams to review technical, operational, and management aspects of the space shuttle program.

After an anticipated resumption of space shuttle flights in July 1987, NASA later announced a postponement of the launch target date to the first quarter of 1988.

The Air Force announced that it would not be using its Vandenberg Launch Site for the space shuttle before 1992. Furthermore, it presently has a program for production and development of expendable launch vehicles with orders for 23 Titan IVs (formerly known as Titan 34D7s) and plans for medium launch vehicles (MLVs).

On August 15, 1986, President Reagan announced that a fourth Orbiter would be built to replace Challenger and that the space shuttle would no longer be used to launch commercial payloads.

The present study is in response to a Congressional request in the aftermath of the Challenger accident, for an assessment of possible space shuttle flight rates and their implications in respect to payloads and the need for expendable launch vehicles.

Approach of the Study Panel

The ad hoc panel met on July 21-22 and August 11-12, 1986, at the National Academy of Sciences in Washington, D.C. In addition, 2 panel members visited the Johnson Space Center (JSC) and 3 visited the Kennedy Space Center (KSC) in connection with information presented to the entire panel. Members also met with Admiral Richard H. Truly, Associate Administrator for Space Flight, at NASA headquarters.

During the meetings, briefings were presented by NASA personnel from the Office of Space Flight and the Office of the Space Station, JSC, the Marshall Space Flight Center (MSFC), and KSC, as well as contractors from Martin Marietta External Tank Division, Rockwell International Corporation, Rocketdyne, the Lockheed Space Operations Company, Grumman, and Morton Thiokol. The panel held discussions with staff from the Office of Management and Budget and the Strategic Defense Initiative Office, as well as with representatives of the commercial communications satellite industry (Hughes Communications Company, RCA Astro-Electronics Company, and Ford Aerospace and Communications Corporation) and the launch vehicle industry (General Dynamics, Martin Marietta, and Arianespace). In addition, much written testimony was received as noted in Appendix G.

Since the study request, 2 events have occurred that affect assumptions: In July 1986, NASA announced there would be a delay of at least 24 months in resumption of shuttle flights, and on August 15, 1986, the President announced the intent to build a fourth Orbiter and to take NASA out of the business of launching private satellites, except under special circumstances. The panel took note of both of these announcements in preparing the following report.

This report states each of the requested assessments followed by the ad hoc panel response. In order to present its findings as clearly as possible, the panel opted to provide concise statements in the body of the report and more extensive background information and details in the appendixes. Subjects covered in greater depth in the appendixes include shuttle launch rates, launch utilization, logistics considerations, cost trade-offs, and the national commitment to a sustained manned spaceflight program.

The report builds upon the 1983 report of the Committee on NASA Scientific and Technological Program Reviews, the Assessment of Constraints on Space Shuttle Launch Rates, which analyzed the individual components determining flight rates.

This report assesses certain specific technical issues but neither endorses nor criticizes the general nature of NASA's programs.

Preamble

This report was requested following the Challenger loss and several months before the President's August 15, 1986, statement announcing intent to build a fourth space shuttle and to end NASA's launching of commercial satellites. The assessments requested in the letter of April 21, 1986, from Congressman Boland to the Administrator of NASA (Appendix A), in the opinion of the ad hoc panel, remain timely but with a few minor changes in assumptions. The 18-month standdown is replaced by a 24-month standdown. The assumption on shuttle launching of commercial satellite payloads is modified to reflect both the near-term shuttle program and manifest and the longer-term intent expressed in the President's statement.

Early in its deliberations, the ad hoc panel found that it had to make an assumption regarding whether the national intent was to have a sustained manned spaceflight program--one in which manned flight was a regular and continuing occurrence year in and year out--or to treat the shuttle fleet as a declining resource (like the Apollo), which in due course would, through use or accident, diminish to zero. It also had to decide whether the requested assessments should apply to the transition period between now and 1991 or to the period thereafter when both the shuttle and ELV fleets presumably would be available for launch.

The panel, considering the nature of the requested assessments, decided to assume a sustained manned flight program and to consider flight rates in both the post-1991 time frame and the build up before 1991. Discussions of these assumptions can be found in the appendixes.

It is the understanding of the panel that the purpose of the assessments is to estimate flight rates for a 3- or 4-Orbiter fleet. Both fleet sizes are therefore addressed without making any recommendation on which fleet size is preferable or needed. (It is clear, however, that the Space Station program has assumed the existence of a "robust shuttle fleet" of at least the 3- or 4-Orbiter size, from which its own flight rate demands would have to be satisfied.)

Congressman Boland's letter also asks for an examination of the assumptions behind the shuttle manifest for the foreseeable future. This matter raises the issue of expendable launch vehicle (ELV) availability--for ELVs are the alternative to shuttle launches. The

Air Force has recently procured a number of heavy-lift ELVs (Titan IVs) and is negotiating to begin production of a medium-lift ELV (MLV). The early production of these vehicles seems likely to be devoted to DoD payloads. Even were production lines for existing ELVs to be reactivated immediately, it would take several years for vehicles to become available. Thus, the availability of ELVs as a shuttle alternative for other than DoD payloads is likely to be severely limited until at least around 1990. NASA and commercial interests have yet to decide to procure ELVs. Thus, particularly in the coming interim period, NASA and commercial interests that have contracted for launch service will be depending on the shuttle as the most immediate launch capability, with corresponding pressure on its manifest.* For activities requiring the specialized use of people, the shuttle cannot be replaced by ELVs.

Before addressing the questions raised by the House Appropriations Committee, the panel will state certain fundamentals drawn from its members' association with research, development, operations, logistics, fleet maintenance, and space activities. These fundamentals must be recognized if shuttle flight rates and manifests are to be discussed without misunderstanding.

One fundamental is that in addressing flight rate, there is an essential distinction between capability and demand. Capability refers to the number of flights that can be mounted given the equipment, people, spare parts, and facilities available. Capability is thus the available supply of launch services. Demand, on the other hand, refers to the number and configuration of payloads to be launched. While this distinction is clear enough, there is often confusion since both capability and demand are discussed in terms of flight rates.

The panel will address the shuttle capability in terms of the sustainable flight rate. This is the rate of flights that can be sustained over a substantial period of time and after buildup from the cautious resumption of flight subsequent to the Challenger accident. This buildup will, of course, require some period of time, perhaps 2 years, before the sustainable rate can be reached.

For short periods of time, a launch rate in excess of that sustainable can be achieved with adequate planning, lead time, and a minimum of changes. The panel will refer to this as the surge rate, recognizing that it places severe stresses on people and facilities. It cannot be sustained for longer than a brief period, approximately 4 months.

The shuttle fleet concept is also fundamental. The fleet Orbiter inventory is the number of Orbiters on hand at any given time; today it is 3. The number of schedulable Orbiters is fewer than the inventory because of a number of fundamental factors, some common with fleets of other flight vehicles such as those operated by the Air Force and commercial airlines (e.g., age of hardware, availability of spares, damage, normal wear). The panel's experience suggests that the schedulable Orbiter fleet is smaller than the inventory by almost one Orbiter. Thus today, the schedulable fleet is only a bit in excess of 2. Therefore, the Orbiter fleet flight rate in the remainder of this report will be calculated on that basis. The reasons for this discounting of the Orbiter inventory arise from essential scheduled maintenance of the flight articles and the possibility of damage or needed modifications to an Orbiter that would keep it or the whole fleet out of service for a significant period.

---

*The statement by the President, dated August 15, 1986, precludes continuing launch of commercial satellites by space shuttle. It appears at this time that certain contracted commitments will be honored.

Reliable, sustainable flight rates hinge upon other factors as well. Underfunded logistics has been a recognized problem for the shuttle program in the past. Today there is still not an adequate complement of spares on hand. This has necessitated cannibalization to keep the fleet flying and has lengthened the turnaround interval for individual Orbiters. In this report the panel attempted to estimate sustainable flight rates based on certain conditions, e.g., adequate spares, logistics, and all the facilities needed for turnaround and training. These conditions will not be necessarily satisfied under programs now in place at NASA. If they are not, a further decrease of sustainable flight rates would be in order.

Another fundamental concern is the industrial base for the manufacture of Orbiters. Because there is a sufficient probability of an Orbiter-involved accident over the operational lifetime of the Orbiter fleet, the capability to produce and repair Orbiters should be maintained. Without it, there will be no viable shuttle fleet. With a small number of flight articles, such as the inventory of Orbiters, no management can sustain a reliable flight schedule since contingencies and new requirements will surely arise from unanticipated events. In other words, the partial equivalent of a contingency Orbiter (one available within a time period that would not seriously disrupt schedules, perhaps 2 years at maximum) should be in the construction process. This is consistent with the President's declaration for a fourth Orbiter and with the panel's judgment that over a period of years (15-20) there must be replacements available because of possible Orbiter wearout (there are no reliable statistics at present on Orbiter life)* or irreparable damage in an accident.

There have been suggestions that a new-technology reusable launch vehicle is in prospect for the 1990-2000 time frame. Even then, any such vehicle is likely to be shuttlelike. Barring an unforeseen, new, space initiative, the panel believes that the shuttle fleet, with improvements, will be required until at least the year 2000 and probably well beyond if the United States is to have a sustained manned space program.

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*Regarding wearout, it is well to note that the Orbiter is stressed near its design limits each time it is launched and returns to Earth. An ordinary airliner is rarely, if ever, so stressed.

On the demand side of shuttle launches, the situation is quite fluid. An important point is that the payload backlog from today's extended launch standdown is not as large as it may appear to be. Many payloads now listed will not be launched at all since they will have missed a window of opportunity. Lack of reliable launch schedules and available insurance for payloads will depress not only future demand, but also the backlog. Just how large this effect will be is difficult to judge. The principal point is that supply and demand will always tend to come into balance.

As launches using shuttles resume, there will be a buildup phase before reaching a sustainable flight rate. This report comments on both phases, but does not attempt to evaluate in detail the buildup operations. However, it is evident that a period of caution will be prudent regardless of the apparent demand for launches and the unavailability of ELVs. Present NASA planning appears to reflect this philosophy.

Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization

The following 4 assessments were requested by Congressman Edward P. Boland in a letter dated April 21, 1986, to NASA Acting Administrator William E. Graham. The request for information is stated, followed by the response of the ad hoc study panel.

ASSESSMENT ONE

> An assessment of the possible flight rate assuming a baseline of an 18-month delay in shuttle operations. The analysis should be based on the assumed flight rate and manifest most recently promulgated by NASA.

Note: Subsequent to the request for this report, NASA announced that the delay would be 24 months from the time of the Challenger accident, and the following responses are based upon that estimate.

Utilizing the current 3-Orbiter inventory, NASA can sustain a flight rate--following a transition phase of approximately 2 years after resumption of shuttle operations--of 8-10 flights per year (Appendix B) from the KSC* under the following conditions:

- no Orbiter is lost or rendered inoperable,
- sufficient logistic support is available to meet the scheduled manifest with reasonable confidence, and
- structural or other system problems requiring substantial, recurring downtime do not occur.

With a 4-Orbiter fleet, the sustainable flight rate would be 11-13 per year; however, there are additional qualifications. The principal constraints to launch rates higher than 8-10 are limits on launch-processing facilities at KSC, limits on mission operations facilities and skilled personnel at JSC, additional time demanded by increased program review and oversight, yet-to-be-defined new safety rules, need for improvement in crew-training facilities, and necessary logistic support (Appendix C).

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*The U.S. Air Force announced that the Vandenberg Launch Site would not be used before 1992. Should it be used for DoD missions thereafter, the yearly flight rates for either 3- or 4-Orbiter fleets would be reduced by approximately one.

The importance of the logistics requirements needs emphasis: to sustain any shuttle flight rate with reasonable confidence requires an adequate inventory of spares, including line replaceable units (LRUs), shop replacement units (SRUs), and expendable parts.* Such items must be available on demand in the shuttle turnaround process. One other limitation should be mentioned: Columbia (OV 102) does not have the performance of the other Orbiters. Many of the Department of Defense (DoD) and NASA payloads require either Atlantis or Discovery, which is effectively a 2-Orbiter fleet for these payloads.

If structural or system problems do occur--contrary to our basic assumption--the sustained flight rate will diminish immediately. This lower rate cannot be calculated because it is dependent upon the particular mission scenario and the severity of the problem. If Orbiters were to require downtimes of several months every few years, outside of planned maintenance, the sustained flight rate for 3 Orbiters would be lower than the 8-10 range. For 4 Orbiters the rate would be lower than 11-13 per year.

Under special conditions, the 3-Orbiter flight rate might surge to approximately 12 per year for a limited period of time, if the major shuttle cargos have standard Payload Assist Module (PAM) or equivalent upper stages, are repeat missions with few flight plan changes, and are launched and landed at KSC. Any mix of other cargo or missions such as classified payloads, Vandenberg Air Force Base (VAFB) launches, Edwards Air Force Base landings, Spacelab flights, rendezvous, or first-of-a-kind missions will reduce the rate to less than 12. For a 4-Orbiter fleet the surge rate may reach 15 flights per year, with stringent operational limitations such as reasonably standard payloads and relatively short mission durations.

The most critical assumption in estimating flight rates is that no Orbiter will be lost or become inoperable for a significant time. The possibility of a loss or irreparable damage to an Orbiter cannot be discounted. In case of loss, the options are to replace the Orbiter or to reduce the flight rate proportionately and permanently. To preclude having a launch capability based on only 2 functional Orbiters for a period that would be at least 5 years, a replacement Orbiter will have to be on order by 1987 for delivery in the early 1990s. Procurement of a fourth Orbiter as announced by the President would fill this need until 1992. Beyond that, some continuing production level to provide replacements will be required since an unutilized manufacturing base will vanish in a very short time.

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*Line replaceable units are shuttle components that can be replaced on the line, e.g., on the launch pad. Shop replacement units are shuttle components that cannot be replaced on the line, but need to be sent back to the shop or the manufacturer.

While maintaining an efficient industrial base implies an order rate for new Orbiters higher than payload demand suggests (Appendix C), it is clear that an accommodation between production and requirements must be reached if replacement vehicles are to be had. The need for additional Orbiters may increase in the 1990s in response to Space Station and other demands, and thus may bring supply and demand into balance. Alternately, the industrial base may function at somewhat less than optimal conditions with spread out production rates. Further study of the maintenance of a viable industrial base is well warranted.

Some concern exists in 3 additional areas that the panel believes need further study: (1) the adequacy of simply upgrading existing training flight simulators when additional, more modern equipment may be required as well, (2) the repeated late addition of payloads to the manifest at the expense of maintaining schedules, and (3) the nature of the shuttle processing contract and the possible need for clearer contractor responsibilities vis-a-vis NASA in quality assurance, spares planning and acquisition, and design change demands on shuttle component designers and manufacturers for reliability and reduced turnaround costs. Until NASA establishes a complete operating organization or elects to contract the total function, these inconsistencies in responsibility will remain a problem.

ASSESSMENT TWO

> An assessment of the assumptions made in.... [partitioning] between payloads manifested on expendable launch vehicles and payloads manifested on the shuttle and whether such assumptions are reasonable.

The following assumptions regarding potential partitioning of payloads between ELVs and the shuttle were deduced by the panel, based upon NASA presentations. The panel did not receive any explicit baseline definitions regarding the partitioning.

It is understood that the manifest for the period from resumption of shuttle flights to approximately 3 years later will be determined on a case-by-case basis within classes of payloads (national security, NASA science and other, and commercial). A number of payloads originally scheduled for the shuttle could be launched by ELVs if these boosters were available; however, only the DoD is committed to build ELVs for this purpose. In the absence of firm shuttle or ELV manifests, the panel examined NASA assumptions regarding payload off-loading, commercial satellites, and availability of launch vehicles.

Payload Off-Loading

The DoD has made a major attempt to off-load free-flying payloads from the shuttle, for example, the Defense Meteorological Satellite Program (DMSP), Defense Support Program (DSP), MILSTAR, and certain classified payloads. Further, DoD may off-load certain additional satellites such as the Defense Satellite Communications System III (DSCS) and Global Positioning Satellites (GSP) replacements. Looking into the far future (mid-1990s), relatively few DoD free-flying payloads will require shuttle launch provided ELVs are available and operational. NASA estimates only 4 such shuttle-unique DoD payloads between resumption of flight and 1993. To this must be added SDI experiments (1 to 2 shuttle equivalents per year beginning in 1989) and potential SDI deployment later. The DoD seems well on its way to relieving its total dependence on the shuttle through ELV procurement.

NASA estimates that approximately 22 of its own payloads could be off-loaded between now and 1993 leaving approximately 110 for shuttle launch. The panel has no reason to doubt the validity of this partitioning. However, in the longer-term future, many payloads could be designed for ELV launch. Based upon the criticality of the Tracking, Data, and Relay Satellites (TDRS) in supporting other missions, NASA should seriously consider launching the TDRS by an appropriate ELV such as the Titan IV. Two TDRSs are presently contemplated for early shuttle launch.

In reference to the planned manifest, the panel notes that no action has been taken by NASA to procure ELVs for its payloads. Lack of funding is one cause for this inaction. Another is the apparent confusion of responsiblities between the space transportation charters of the Departments of Commerce and Transportation and NASA. Also NASA has not as yet stated a policy for partitioning its payloads between the shuttle and ELVs. It seems true that many people in the space science community* would prefer ELV launch because of past experience with shuttle uncertainties and costs. This preference is not yet being taken into account by NASA. It is important to note here that, as presently designed, the NASA Space Station alone could require 8-10 shuttle flights per year for deployment and support in the middle 1990s.

Commercial Satellites

The commercial satellite situation is confused by existing contractual commitments for launch by NASA. The assumption is that shuttle launches of commercial satellites with existing contracts will continue. It is hoped, but not yet planned, that significant numbers of ELVs will become available in the future for the commercial market. The competitors for the proposed DoD medium-lift launch vehicles (MLVs) have indicated these vehicles could be ready by early 1989; however it will be several years after that before new ELVs become available to users other than DoD. The primary requirement of commercial satellite users, in addition to a launch reliability of more than 93 percent (the approximate reliability of past ELVs), is availability of timely launch. Assuming availability, most commercial satellite suppliers and operators now express preference for ELVs. The panel believes that the assumption of availability is open to question. The economic viability of commercial launch suppliers may not be decided for many years because of the long transition period from total shuttle dependence to some combination of foreign and speculative domestic suppliers.

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*This is with the exception of scientists involved in some aspects of earth, life, and astronomical sciences and in space-processing research.

Also, the longer-term demand for commercial launches is nebulous at best. At the present, 44 commercial payloads are contracted for NASA launch; another 46 have made lesser commitments. Though many of these will fall by the wayside because of the delay and uncertainty, others will retain their reservation and lobby for shuttle launch if the contracted costs are maintainted. Still others will move to Ariane or other foreign launchers. However, demand will decline because of the difficulties: launch supply and demand will tend to come into balance. As contemplated today, approximately 15 commercial shuttle launches are anticipated between resumption of flight and 1993. To the panel, this rate of commercial utilization seems significantly too low if additional DoD and NASA off-loading to early ELVs becomes possible.

Availability of Launch Vehicles

It has been implicitly assumed that launch vehicle production (whether of shuttles or ELVs) could keep up with demand, regardless of the mix of shuttle and ELV launches. The matter of shuttle production and support was addressed earlier. ELV procurement is limited at present to DoD. Representatives from the launch vehicle industry indicate adequate numbers of ELVs for DoD, NASA, and commercial needs could become available, with present or slightly expanded production facilities within 3 to 4 years of orders. Thus ELV production capability does not seem to be a limit, at least in the long run, to future space activities. As for timing, ELVs for the military will be available within 3 years after the contracts are signed. However, because of DoD needs, and government budget limitations, it seems unlikely that ELVs could be available for commercial payloads before the early 1990s.* Arianespace representatives stated that Ariane is completely booked until after 1990 as well. Thus, there is a time gap of several years before a commercial launch capability could be available to meet the needs of commercial payloads, despite adequate production and launch facilities.

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*It is noted that in September 1986 a commercial company contracted with Federal Express to launch a private payload in 1989.

ASSESSMENT THREE

> An assessment of the impact on both flight rate and manifest of the existing 3-Orbiter fleet with no fourth Orbiter replacement. This assessment should include manifest requirements for both launch and operation of a Space Station. This assessment should also be based on the assumption that the shuttle will fly at least one-third of the average number of commercial satellites launched over the manifest period.

As stated in the the first assessment, the panel believes that a sustained flight rate of 8-10 per year for a 3-Orbiter inventory and 11-13 for 4 Orbiters can be maintained only under the conditions previously noted. Support of a Space Station requires a robust shuttle fleet, even were a new Space Station design to reduce launch requirements. The panel does not consider a 3-Orbiter fleet robust because of accident possibilities and other needs for downtime. Given the assumptions presented by the Space Station office, the entire 3-shuttle capability would be absorbed by this project, i.e. a need for 32 shuttle flights is projected for the initial 3-year construction phase. However, the construction and operation of the station is still under study and these estimates may be modified. Although some ELVs could be used for purely cargo flights, operating the Space Station adds another requirement, nearly the same weight must be returned from orbit as was originally launched to orbit in the operational phase, a requirement not met in ELV designs.

Estimates of the number of commercial satellites that will be shuttle-launched in the 1990s are difficult in today's uncertain launch and insurance environment. However, NASA has indicated that some 15 commercial launches will be available between resumption of flight and 1993. This is about one-third of the 44 contracted launches. Others beyond contracted payloads number 46. To launch one-third of all commercial payloads would require 30 launches. This number is not possible given the current situation. However, a resolute effort by the federal government to accelerate production, and procurement of ELVs would allow for more commercial launches in the period before potential privately supplied launches could become available. Clearly, there is a need to proceed with ELV procurement for NASA payloads and for fulfilling contractual obligations to commercial operators. Competitive pricing of ELV launches with shuttle and foreign suppliers should be a principal consideration.

ASSESSMENT FOUR

An estimate, based on available data, of the various cost trade-offs of the above assumptions.

Due to the many political, financial, and market variables in the immediate post-Challenger environment, it is not possible to make detailed cost trade-off analyses at this time. Nonetheless, one general statement can be made.

Total national space launch costs depend principally upon the size of the nation's space program. Perhaps surprisingly, the total launch costs are relatively independent of the particular mix between shuttles, Titan IVs, MLVs and Titan IIs (for example) for a given total weight to orbit in equivalent shuttle loads (Appendix E). In other words, policy decisions such as the long-term commitment to man's presence in space (Appendix F), the timing and cost of a Space Station, the nature of the SDI, and the robustness (spares on orbit and survivability) of national security space systems will have a greater effect on national launch costs than the shuttle/ELV mix.

Summary

POLICY ASSUMPTIONS

1. The United States will have a sustained manned space launch capability.
2. The present shuttle will have to assure that function at least until the turn of the century.
3. An ELV production commitment will be made to achieve a mixed fleet of launchers.

FLIGHT RATES

Three Orbiters can sustain a rate of 8 to 10 flights per year after an initial buildup period of approximately 2 years providing: (1) no Orbiter is lost or becomes inoperable, (2) adequate logistics support exists, and (3) no problems exist that require extensive downtime. A surge rate of 12 flights per year should be possible for short periods of time for simple payloads and flight plans.

With a 4-Orbiter fleet the sustainable flight rate would be 11-13 per year with a surge rate of 15 flights per year only if appropriate ground support facilities are acquired.

In order to sustain such rates and take account of possible contingencies, the shuttle scheduling should be based upon fewer vehicles than are actually in the inventory by almost one Orbiter.

FLEET CONCEPT

If the space shuttle is to serve manned launch requirements for an extended period of time, then it should be viewed in terms of a fleet in the same manner as other transportation systems and consideration must be given to vehicle attrition necessitating replacement Orbiters over time. This will necessitate a balance between production rates and replacement requirements.

LAUNCH DEMAND

With the temporary cessation of shuttle flights, it is expected that the backlog of manifested payloads will actually decrease as some previously scheduled satellites will not be flown and the DoD will off-load many payloads for launch on ELVs.

The heaviest launch demand arises for the Space Station--32 shuttle launches are anticipated during the 3-year construction phase--and, presuming schedules do not slip, this could not in itself be accommodated by 3 Orbiters. This situation is recognized by NASA study groups currently reexamining the configuration of the Station.

While many military payloads are slated for launch on the Titan IV and the MLV, there is not an ELV launch capability to accommodate the large number of space science or commercially contracted payloads. A resolute ELV procurement effort by NASA, or other civil government agency, is not yet in place but may be required to fulfill commercial contracts and NASA's space science program. Unless or until a commercial launch vehicle industry comes into existence, however, an extensive private launch industry is not likely to arise before the 1990s.

PAYLOAD PARTITIONING

Partitioning of payloads between the shuttle and ELVs has been materially affected because NASA is not funded at present to procure ELVs. Even in the short run, some additional off-loading of DoD-related payloads may be in order when alternatives are available.

Appendixes

Appendix A

Background

1. April 21, 1986, Letter from Congressman Edward P. Boland
2. List of Briefers and Participants
3. Committee on NASA Scientific and Technological Program Reviews Membership

Congreſs of the United States
House of Representatives
Committee on Appropriations
Washington, DC 20515

April 21, 1986

Honorable William E. Graham
Acting Administrator
National Aeronautics and Space
  Administration
Washington, DC   20546

Dear Dr. Graham:

I am writing to request that NASA call upon the National Research Council (NRC) Committee on NASA Program Reviews, to examine the future implications and possible scenerios resulting from the tragic loss of Challenger.

Specifically, it is requested that the following information be provided by the NRC:

1. An assessment of the possible flight rate assuming a base line of an 18-month delay in shuttle operations. The analysis should be based on the assumed flight rate and manifest most recently promulgated by NASA.
2. An assessment of the assumptions made in the above flight rate between payloads manifested on expendable launch vehicles and payloads manifested on the shuttle -- and whether such assumptions are reasonable.
3. An assessment of the impact on both flight rate and manifest of the existing three orbiter fleet with no fourth orbiter replacement. This assessment should include manifest requirements for both launch and

Honorable William E. Graham
April 21, 1986
Page Two

operation of a space station. The assessment should also be based on the assumption that the shuttle will fly at least one-third of the average number of commercial satellites launched over the manifest period.

4. An estimate, based on available data, of the various cost trade-offs of the above assumptions.

I would appreciate your cooperation in forwarding this request and in assisting with the study. A report covering these issues should be available to the House Appropriations Committee by October 15, 1986.

Sincerely,

Edward P. Boland
Chairman
House Subcommittee on HUD-
Independent Agencies

LIST OF BRIEFERS AND PARTICIPANTS

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William Franklin, Technical Advisor, Launch and Landing Operations
John P. Hodge, Deputy Associate Administrator for Space Station
Ron Kinsley, Program Manager, Shuttle Payloads
Chester M. Lee, Director, Customer Services

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Robert Glaysher, Vice President for Shuttle Operations, Downey, California
Leroy D. Solid, Director of Launch Operations, Kennedy Space Center, Florida
Don L. Steelman, Director, Customer Representation, Washington, D.C.

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Appendix B

SHUTTLE LAUNCH RATES

A detailed assessment of space shuttle launch rates was provided in an earlier report issued in April 1983 under the Committee on NASA Scientific and Technological Program Reviews, Assessment of Constraints on Space Shuttle Launch Rates. The present study takes into account lessons learned over the past 3 years, including circumstances following the loss of the Challenger on January 28, 1986.

During its short passage through the sensible atmosphere, the shuttle is stressed far nearer its design limits on every flight than is the case for transport aircraft, for which such an occurence is a rarity. Also, there are considerable differences between individual shuttle missions, unlike the repetitiveness of airline or more routine military operations. A shuttle flight manifest utilizing maximum possible turnaround rates must not compromise safety standards, since each flight is working so closely to the vehicle performance limits. The need for adequate safety reviews, logistics support (see Appendix C), spare parts, extensive inspection and maintenance, and extreme care in every facet of the turnaround operation cannot be overemphasized. In addition, sufficient crew-training facilities--including simulators and training aircraft--are needed to enable adequate training flowthrough to meet projected flight rates.

Present ground facilities at KSC with planned augmentation--e.g., the Orbiter Maintenance Facility--appear adequate to handle flight rates up to 12 per year. However, manpower at Johnson Space Center and spare parts production would have to be increased for such flight rates. The single Shuttle Processing Contractor (SPC) concept presently in place appears to be advantageous from an administrative point of view. While the SPC has improved in technical competence over the past 2 years, it still requires further improvement in the handling of individual systems--(Space Shuttle Main Engine, Solid Rocket Booster, External Tank, and Orbiter).

Crew training facilities and software development need improvement for flight rates up to 12 per year. Needed are an upgrading of existing facilities and an increase in the number of simulators as well as a fourth shuttle training aircraft.*

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*See Assessment of Constraints on Space Shuttle Launch Rates, National Research Council, 1983.

With Orbiter landings at Edwards Air Force Base for the foreseeable future, and a projected 18-month delay in procurement, an additional Shuttle Carrier Aircraft would be prudent.

Experience gained in the STS program, and from the accident, suggests that a sustained flight rate per Orbiter on a long-term basis should be more conservative than was thought necessary no more than 2 years ago.

The estimates given below are based on launch from KSC. The DoD shuttle launch complex at Vandenberg Air Force Base on the West Coast is being placed in "caretaker" status until 1992 according to Secretary of the Air Force Edward Aldridge.* Use of this complex for shuttle launches in the years beyond 1992 remains an open question.

Turnaround time

Shuttle turnaround time consists of 4 main elements: (1) processing time at the Kennedy Space Center, (2) mission duration, (3) transit time to ferry the Orbiter to KSC (if it lands elsewhere), and (4) planned periodic inspection and maintenance. These elements can be quantified on an average basis. A fifth element that cannot be quantified consists of contingencies--major damage to, or loss of, an Orbiter; diverted landing; weather delays; late manifest and/or flight plan changes; unforeseen payload delays; facility or support system downtime; lack of timely availability of spares/logistic support.

Shuttle processing at the KSC takes place successively in the Orbiter Processing Facility (OPF), the Vehicle Assembly Building (VAB), and on the launch pad (PAD). To be added in the near term is an Orbiter Maintenance Refurbishment Facility (OMRF) through which the Orbiters will flow on their way to the OPFs. The average shuttle processing time to date at the KSC has been 75 work days; the shortest was 46 work days. The latter is viewed as representing a surge condition and not a sustainable one. The former is viewed as an average conservative sustainable processing time. A more optimistic, but not unrealistic sustainable processing time would be 20 percent shorter, or 60 working days. Both are shown in breakdown in Figure B-1.

Average mission duration is estimated to be 7 days. Since Orbiter flights will be landing at Edwards Air Force Base for the foreseeable future, account is taken of ferrying time (including one day for weather uncertainties) of 6 days. Planned structural inspections and major maintenance are expected to require on average the equivalent of 2 weeks of downtime for every flight.

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*"Air Force Secretary Describes Defense Department Space Recovery Plans," Press release dated July 31, 1986.

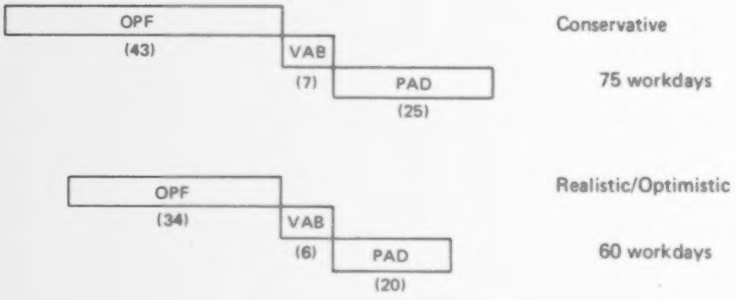

Figure B-1 Shuttle Processing Time.

With regard to the work week, bearing in mind the emphasis on safety and efficiency, it is postulated that ground crews work a 3-shift per day, 5-day week. The panel regarded a scheduled 7-day work week as undesirable over the long term because of the possible impact on flight safety.

Flight Rates

Based on the estimates above, the 75-work-day processing time results in an average number of flights per year per Orbiter of 2.7. With an improved processing time of 60 work days, the average rate per year per Orbiter becomes 3.3 (assuming a normal 3-shift, 5-day work week).

Thus, the average yearly sustainable flight rate for a 3-Orbiter fleet is 8 to 10. For a 4-Orbiter fleet the sustainable rate becomes 11 to 13 per year.

The above estimates apply to the KSC. Should the Vandenberg Launch Site be utilized for DoD missions after 1992, the U.S. Air Force expects to have one to 3 shuttle launches per year from the site. It is also expected that one Orbiter equivalent would be dedicated to Vandenberg. The effect would be to lower the flight rates noted above by approximately one flight/year--i.e., 7-9 for a 3-Orbiter fleet and 10-12 for a 4-Orbiter fleet.

It should be noted that these estimates do not account for contingencies noted earlier. While there is no way of predicting possible time lost due to some contingency or other, the experience of airlines and of U.S. Air Force aircraft operations shows that backup vehicles are needed to allow schedules to be maintained when an unforeseen event puts a vehicle out of commission.

Appendix C

LOGISTICS CONSIDERATIONS

The shuttle in 1986 has accomplished a long series of successful operational flights. Nonetheless, from a technical point of view, it is not yet out of the development phase. Design flaws, expected in a system of this complexity, are still being corrected. The spares complement is just being developed for main engines, solid rocket boosters, other line replacement units (LRUs), and so forth. In that respect, the past operational flights have been essential to determining the real, as opposed to the hypothetical, logistics needs for various sustainable flight rates. Consequently, a more efficient logistics program can now be set up than was possible some years ago. By the 1990s, most major development should be completed and the logistics picture should have stabilized. This appendix endeavors to estimate what that picture will be.

The panel accepts NASA's estimates of the immediate logistics needs. However, NASA has not systematically examined the consequences of the eventual loss, through use or accident, of Orbiters. Such losses must be expected, as NASA itself has stated in testimony on the Challenger loss. The complexity and uniqueness of the shuttle (critical elements, design margins, "rebuild" for every flight, etc.) reinforce that point. Well-recognized calculations relating system reliability, confidence level in accomplishing the mission, fleet size, and flight rate (equipment lifetime) have been used for years to determine the buy rate for aircraft, satellites, and other fleets. Figures C-1 and C-2 show the relationships among these factors for the range of parameters applicable to Orbiters. Figure C-1 shows the situation assuming no Orbiter losses: the upper curve gives an upper bound on flight rates per year so that there is a 50 percent chance of no Orbiter loss over the period. The lower curve represents an upper bound for a 90 percent chance of no loss. Figure C-2 shows the situation assuming one loss, i.e., the upper bounds on flight rates for no more than one Orbiter loss during the period. ("Loss" may be through wear out, severe overstress, or any accident that precludes further use.) An alternate way of showing the information in Figure C-1 is given in C-3. Based on all experience to date, one would have to have unachievable reliability to have a high confidence manifest without some planned backup, workaround and/or replacement Orbiter.

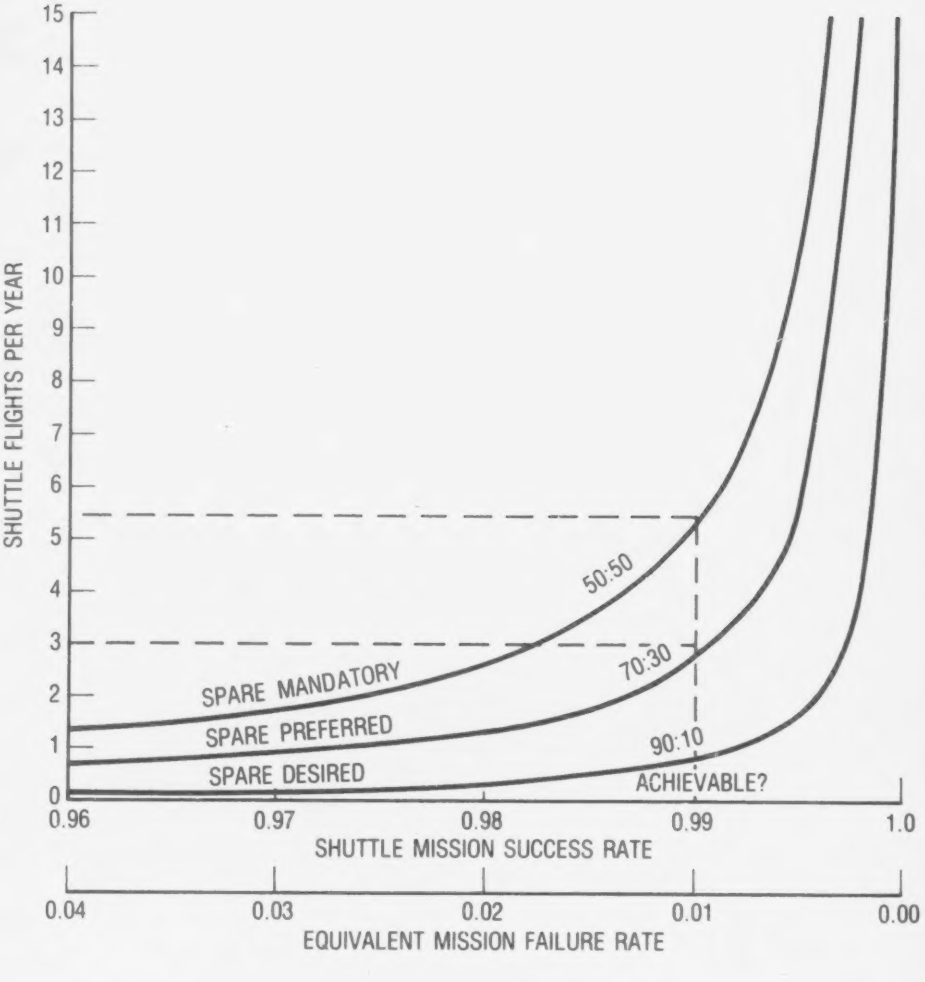

Figure C-1 The Chances of Losing Zero Orbiters 1988 through 2000 Time Period.

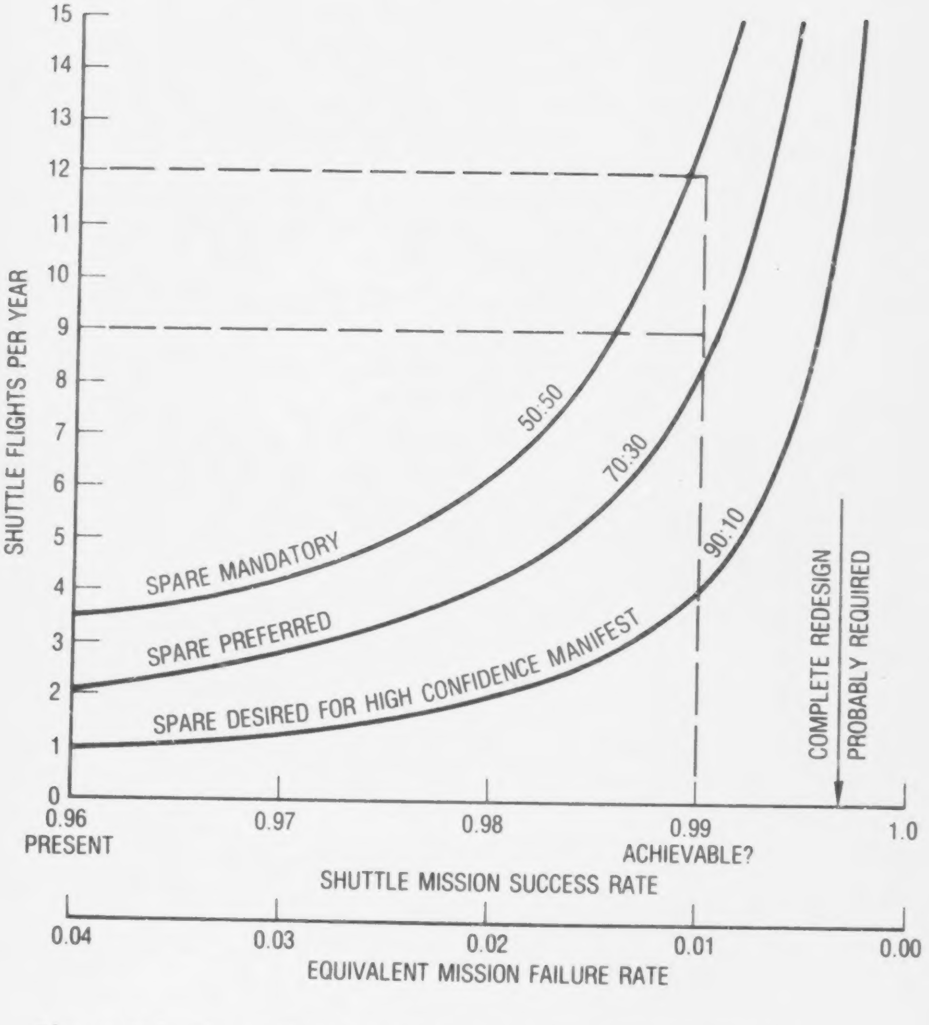

Figure C-2 The Chances of Losing No More than One Orbiter 1988 through 2000 Time Period.

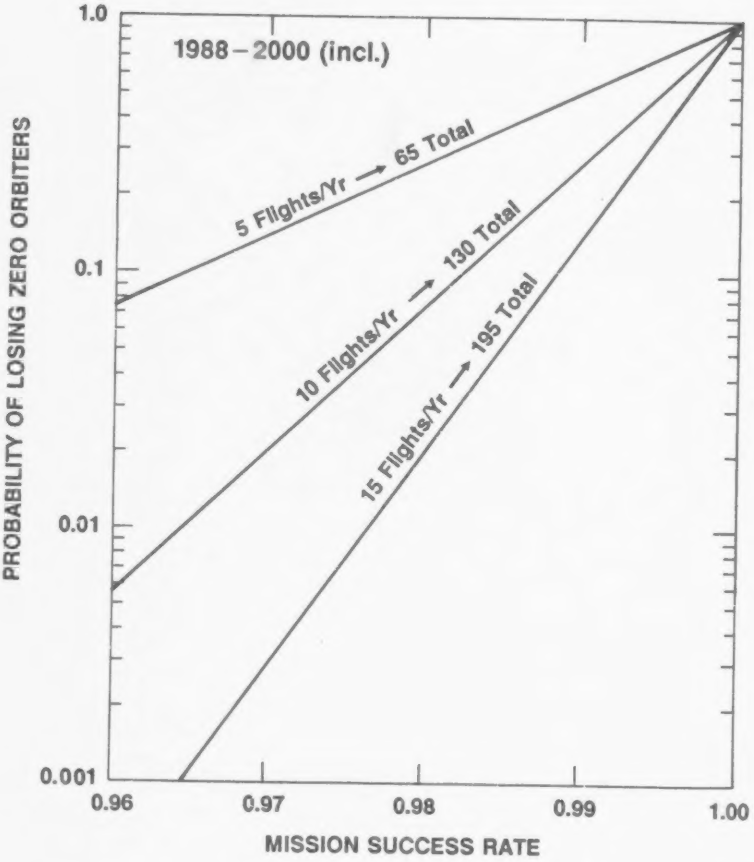

Figure C-3 (An Alternative View of the Information in Figure C-1.)

The shuttle system reliability to date is 0.96 (a failure rate of 4 percent). Given NASA's vigorous efforts at improved safety, this failure rate might be cut by a factor of 4; reducing it by a factor of 10 to a reliability of 0.996 is most unlikely in a short time or for costs less than the development cost to date (based on aircraft development experience).

It is important here to distinguish between having sufficient LRU spares and replacing a lost Orbiter.* The former is planned by NASA with appropriate budget requests; it is crucial for maintaining an acceptable Orbiter turnaround time. But, it assumes infinite life for the airframe, major structural components, and fittings. A noncatastrophic failure of an LRU--even if the cause were a design problem that grounds the Orbiter fleet for a while--is unlikely to affect the flight schedule for much more than a year. (The Challenger solid rocket problem will take somewhat longer but past ELV experience suggests that this is an exception.) Such schedule disruption can be accommodated through increased satellite design life of more than 5 years, as well as spares on orbit; planetary and space station programs clearly have more difficulty accommodating delays.

The loss of an Orbiter, however, as demonstrated by the Challenger accident, has long-lasting effects on all missions. Missions are placed in jeopardy. Mission and industrial teams are in danger of breaking up, especially university scientific teams and subcontractor teams. Time-critical satellites may be mothballed or discarded. The collateral costs are already a major fraction of the cost of another Orbiter. Yet this kind of disruption is inherent with small fleets of reusable, fully-booked vehicles with long replacement times.

There are several possibilities for minimizing the severity of impacts. First, a full-up spare Orbiter, with another ordered later, would help alleviate the buildup of backlogs if the anomaly is not a systems design-related one. Satellite constellations, for example, frequently have spares on orbit, but such an alternative for the shuttle may be too expensive. Another, albeit riskier, possibility is a flight rate sufficiently below the maximum rate where a multiyear "surge" could alleviate schedule conflicts until a replacement Orbiter is brought on line. Shifting of "standard" dual-compatible satellites to ELVs along with a sufficient inventory of "ready-to-go" vehicles, might help.

In any case, without an agreed strategy to accommodate Orbiter loss, long-term confidence in any shuttle manifest is certainly limited. This could be crucial for the space station, planetary launches, and some national security flights.

The Report of the Presidential Commission on the Space Shuttle Challenger Accident and the statements of individuals who met with the panel identified a number of relatively short-term problems that the panel believes NASA is likely to solve by the early 1990's:

- The cannibalization of LRUs from one Orbiter for parts or repair of other Orbiters (on the order of 50 percent on past flights).
- Limitations on nondestructive testing.

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*The NASA spares program does not supply a full "ship set" of spares, some of which have very long lead times. Consequently, a replacement Orbiter cannot be built just out of spares.

- Main engine and landing gear replacement and repair provisions.
- Flight simulator limitations (technological and capacity).
- Critical skills, spares, and maintenance requirements at KSC.
- Critical skills, simulators, data storage and software development at JSC.
- Establishment of a long-range logistics support plan, updated annually or as experience dictates. General concurrence in the plan and its financing by the Executive and Legislative Branches.
- Agreement by the NASA and DoD as to which payloads would be compatible with both Orbiter and ELVs. In this connection, it is not necessary that all payloads be dual compatible in order to assure access to space. But those that are will require advance planning of launch support if changeover is to be practical.

The panel also notes the continuing trend toward the formation of a Shuttle Operations Organization, which could be an important factor in achieving confidence in any shuttle manifest.

A serious limitation to a reliable manifest is the maintenance of an industrial base to support the spares and replacement needs of the shuttle fleet. The shuttle fleet is a small one, with a low replacement rate. But according to Rockwell International, to ensure that a replacement Orbiter is available within, say, an 18-24 month call-up would require a production capability of 2 Orbiters on order all the time (or 1 every 2 years). However, an efficient industrial base can be maintained with a production rate of one Orbiter about every 3 years along with continued production of spare parts. But with an Orbiter fleet operating at about 10 flights per year and a loss rate of 1 to 2 percent, the replacement order rate would be one every 5 to 10 years, too low to retain an efficient industrial base. Increasing the shuttle's reliability to the point of not needing any further replacements nor an industrial base is not practical (see Figure C-1).

A compromise would be a shuttle production rate of about one Orbiter every 4 years along with a national commitment to aggressive use of shuttle-unique capabilities.

Appendix D

SHUTTLE UTILIZATION

Before the loss of Challenger, the shuttle fleet was fully booked. There were even indications that shuttle was overbooked. Presentations to the panel from several sources indicated that the demonstrated flight rate of 10-12 flights per year was severely stressing shuttle operations capabilities at all the affected NASA centers. The future manifest through 1991 indicated a still higher flight rate.

Post Challenger, the achievable fleet manifest will be significantly less than the pre-Challenger manifest. The difference between the 2 is usually called the "backlog." If accepted at face value, this backlog would call for flight rates approaching 20 per year well into the 1990s in order to reduce it to zero. Some immediate relief was obtained by off-loading payloads to ELVs, a more vigorous action by the DoD than NASA but done nonetheless. The August 15, 1986 Statement by the President indicates that commercial satellites in the 1990s (once the post-Challenger transition is completed) also will be off-loaded. The panel anticipates further reduction of the backload by acknowledging that satellites not launched during the transition phase represent "services not delivered," i.e., the blocks of satellites that were to be launched will simply be pushed out in time and future buys reduced accordingly. Some satellites may simply not be launched at all--by the time they could be launched they would be obsolete for the purpose they were to serve.

The backlog is also likely to be reduced by what is called "discounting" of the future manifest. Experience shows that launch schedules a year or more in advance are likely to be too great by about 30 percent. The reasons have to do with delays in payload delivery, unscheduled downtime of the launch vehicles, cancellation or stretchout of programs for funding reasons, etc. Whatever the cause, the discounting phenomenon is well documented for both shuttle and ELV fleets.

Another clear factor in the size of the backlog, at least in the past, is the price charged for a shuttle launch. (There are more customers for a free launch than for a "recovered cost" launch.) Reduced flight rates and reduced performance will increase per-flight costs relative to ELVs for customers charged for shuttle service.

The question then remains of what flight rate reasonably matches both the capability of a shuttle fleet and a realistic utilization (demand). From a purely technical point of view (i.e., putting aside funding considerations), there will clearly be a demand for man-critical flights such as Spacelabs, life and earth science experiments, recovery and repair missions. There will be a demand for shuttle-unique missions (sorties, short-duration on-orbit R&D, and certain classified low-orbit missions). Collectively, these might amount to 3 or 4 flights per year.

The demand for physical sciences was initially very high, particularly since physical sciences missions weren't assessed launch costs as part of project costs. But a severe disenchantment has set in with unexpected costs, procedures, man-rating specifications and delays, particularly for physical science missions that could be done at least as well, if not better, technically on free flyers launched by ELVs. In the long run, the demand will be for a launch capability that preserves the momentum and opportunity for engaging outstanding scientific talent in meaningful research. Therefore, until the shuttle is seen to fulfill its original purpose, the demand for physical sciences flights is likely to drop. In the short run, the physical sciences utilization may well be determined by the price, if any, that such missions are assessed for launch costs. Priorities being what they are, the utilization rate of shuttle for physical sciences might be a 1-2 equivalent shuttle flights per year. (Note: The number of payloads considerably exceeds the number of equivalent shuttle flights.)

The greatest change in utilization, however, is likely for geosynchronous and other high-altitude missions. For these missions, the shuttle is "just a truck." If fully costed, it is an expensive truck. With the cancellation of Centaur as a shuttle-compatible upper stage, the shuttle is, at least temporarily, no longer a high-performance path to high orbit. The ELVs should be expected to take over much of that capability. Where lesser performance is acceptable, cost may be the determinate. As noted in Appendix E, the total national launch cost is relatively independent of the shuttle-ELV mix, implying that customers could choose what appeared most cost effective to them. Many, but perhaps not all, would opt for ELVs, depending on the price and availability of the various future launch options.

The demand for the shuttle for Space Station launches was, until recently, relatively high--8-10 flights per year. Testimony of John Hodge to the House Subcommittee on Space Science and Applications (July 21, 1986) indicated that "Depending upon the future composition of this Nation's space launch fleet, it would be possible that the current Space Station would need to use both the shuttle and expendable launch vehicles in support of Space Station needs." It is the panel's estimate that the demand in the 1990s to support the current Space Station design will be roughly equivalent to 2 more Orbiters with an appropriate provision for a replacement if and when needed. It wouldn't be surprising if 1-2 flights per year were required for experimental purposes prior to the increased flight rate during construction.

Estimating the demand for the Strategic Defense Initiative (SDI) is best done in 2 parts. Barring drastic changes in the SDI program, there will be a continuing need for research flights requiring manned intervention, sortie, recovery and repair missions--essentially "proof-of-concept" flights of technologically very advanced systems. The shuttle could be a good match to these systems, especially if it is important to bring them back for analysis and modification. The SDI Office, however, estimates its utilization at only 1-2 flights per year for less than 10 years and no shuttle use in the deployment phase. However, even if the decision were made early in the 1990s to go into full-scale development, the impact on the shuttle fleet wouldn't be felt for at least 5 years. A more likely occurrence would be the development of a new launch vehicle (heavy lift, unmanned?) specifically for SDI weight lifting.

One major consideration suggests a significantly reduced shuttle utilization as compared with the NASA manifests. Projected costs in the 1990s of the NASA civil mission model (payloads and transportation) used in the NASA/DoD Space Transportation Architecture Study show a "bow wave" in costs far above likely funding, dropping well below later, indicating a major shift of programs into the next decade.

All things considered, a rate of 8-10 flights per year in the early to mid-1990s, prior to the construction of the Space Station, does not appear to be much off the track for a well-operated shuttle fleet of 3 Orbiters. If the demand turns out to be greater, the primary long lead item will be another Orbiter.

Appendix E

COST TRADE-OFFS

Reliable cost figures are difficult to come by at this time. Shuttle redesign, replacement, and operations costs are in flux. Titan IV, MLV, and Titan II costs either are being renegotiated or are competition-sensitive. The best that can be done is to use existing NASA and Air Force cost data bases and should-cost models to determine the likely cost drivers. While by no means accurate enough for budget purposes, their use in the past has proven useful in determining first-order trade-offs, i.e., more refined subsequent calculations seldom overturn the general results. The calculations were performed by the Aerospace Corporation.

Figures E-1 and E-2 indicate the total launch costs of various mixes (see Table E-1) of shuttles (STS), Titan IVs, medium-launch vehicles (MLVs) and Titan IIs corresponding respectively to 24 and 16 equivalent shuttle flight loads per year depending upon the annual depreciation assumed for the shuttle fleet. Depreciation includes the cost of replacements Orbiters regardless of cause.

Comparing the 2 figures, the total costs clearly depend upon the total flight load; it costs more to launch 24 than to launch 16 shuttle-equivalent flight loads per year, though the increase is not proportional.

Taking either figure, it doesn't make much difference what mix is chosen, though at more than a one percent depreciation it costs less to have fewer rather than more shuttles in the mix. Such differences as occur may well be within the estimating accuracy. The calculations assume that each mix is stable, i.e., changes from one mix to another could generate added costs unless the changes were well planned in advance. In any case, a commonly held assumption that ELV costs are simply an add-on to the (fixed) costs of the shuttle program is not substantiated by the available data bases and cost models when all costs are considered.

What is more important to total cost, again taking either figure, is the depreciation rate for the shuttle fleet. Based on the logistics considerations discussed in Appendix C, the depreciation rate one might expect is in the range of 1-2 percent. The clear cost trade-off here is between higher (and earlier) reliability improvement costs and higher (and later) depreciation costs. Safety will drive to the former; near-term funding and schedule pressure could drive to the latter.

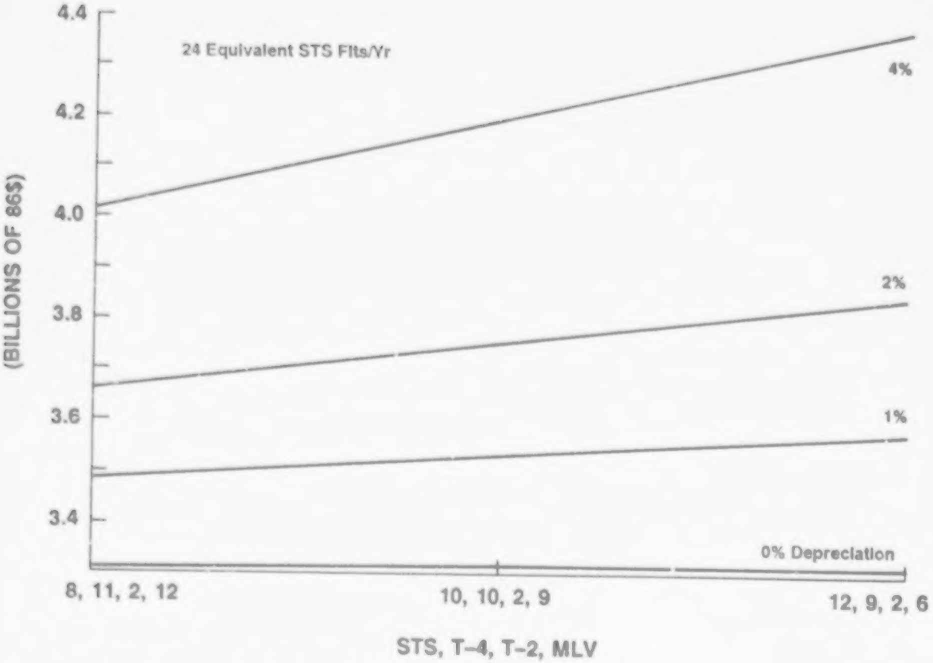

Figure E-1 Total Cost Trends--Mixed Fleet Options Studied (Case I)

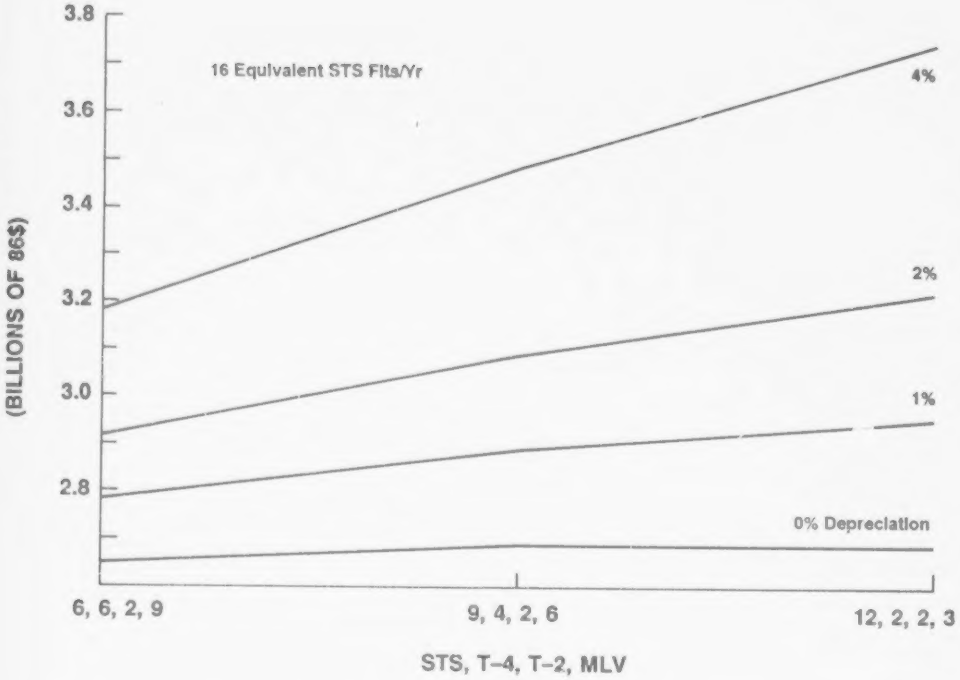

Figure E-2 Total Cost Trends--Mixed Fleet Options Studied (Case II)

TABLE I NATIONAL DEMAND MODEL POST FY-91

CASE I:	TOTAL DEMAND OF 24 EQUIVALENT STS FLIGHTS			
	STS	8	10	12
	TIV	11	10	9
	TII	2	2	2
	MLV	12	9	6
CASE II:	TOTAL DEMAND OF 16 EQUIVALENT STS FLIGHTS			
	STS	6	9	12
	TIV	6	4	2
	TII	9	6	2
	MLV	6	3	3

CASE I is a discounted version of the national demand presented by NASA Headquarters (J. Fitts).

CASE II is a much more conservative version of the national demand.

Appendix F

A SUSTAINED MANNED SPACEFLIGHT PROGRAM

Perhaps the single most important assumption made in this report is that the nation is committed to a sustained manned spaceflight program. If true, that commitment has direct consequences to shuttle operations. In particular, unless the shuttle fleet is maintained during the 1990s at approximately the realistic flight rates given in this report, the necessary foundations will not exist for manned Space Stations, SDI in-flight development, testing of tactical intelligence and battle management concepts, clinical research, countermeasure testing related to space adaptation, and development materials-processing systems that depend on the space environment.

The realistic or sustainable flight rates in this report are based on supply constraints and mission demands for presently committed missions, not those still in conceptual design. For example, Space Station needs cannot be supported without what the Space Station Director properly calls a "robust shuttle fleet."

The assumption of a national commitment to a sustained manned spaceflight program would be self-evident were not an alternative under discussion in the government. This alternative would not replace the present Orbiter fleet (either 3 or 4 Orbiters) when and as needed but would let the shuttle fleet decrease through attrition, relying on a future vehicle fleet of more advanced vehicles to pick up the manned flight effort and on ELVs to launch all payloads not requiring astronaut intervention. The advanced manned vehicle usually mentioned is the National Aerospace Plane (NASP), though a modified shuttle (high safety, minimal cargo) is also being discussed.

One difficulty with the alternative assumption (shuttle attrition) is timing. As the shuttle is demonstrating, it takes at least a decade to develop a space vehicle to the point of reliable operation even when the technology is believed to be in hand. Technology for the National Aerospace Plane is not yet in hand and the size of the vehicle contemplated for the turn of the century is too small to handle shuttle-equivalent payloads. Modifications to the shuttle are under study, but they are not yet past the conceptual design phase. The alternate assumption, therefore, would predictably result in a hiatus (5 to 10 years) in manned flight, precluding the Space Station planned for the 1990s.

A more serious difficulty, however, would be the imminent collapse of the shuttle manifest. As discussed in Appendix C, at 10 flights per year and a 1-2 percent loss rate, but with no replacements, the shuttle fleet would be down one Orbiter in about 5 years and down 2 in 10 with corresponding flight rates of 7 and 4, respectively, per year. Those rates would hardly handle the man-critical missions. In anticipation of an uncertain launch future and to protect their missions, mission directors would no longer design shuttle unique payloads and for planning purposes would schedule on ELVs. ELV production facilities would expand accordingly. Thus, even before any losses might occur, the uncertainty in the future of the shuttle fleet could result in a collapse of the 1990s manifest and an increased cost per flight, which would deal manned space flight a serious blow.

Appendix G

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